Food and Agricultural Research Council

Proceedings Fourth Annual Meeting of Agricultural Scientists

Réduit, Mauritius,
21 – 22 October 1999

FOOD AND AGRICULTURAL RESEARCH COUNCIL

P R O C E E D I N G S

FOURTH ANNUAL MEETING
OF
AGRICULTURAL SCIENTISTS

REDUIT, MAURITIUS, 21-22 OCTOBER 1999

February 2001

P R O C E E D I N G S

Fourth Annual Meeting of Agricultural Scientists

Bonâme Hall,MSIRI
Réduit, Mauritius, 21-22 October 1999

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 2000

SUGGESTED CITATION :

LALOUETTE JA, BACHRAZ DY and SUKURDEEP N. eds. 2000. *Proceedings of the Fourth Annual Meeting of Agricultural Scientists*, Réduit, Mauritius, 21 – 22 October 1999. Réduit, Mauritius : Food and Agricultural Research Council.

ISBN

PARTICIPATING INSTITUTIONS 1999

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.

TABLE OF CONTENTS 1999

Session 4 – Chairman *Mr Jean Noël Humbert*

Session 5 – Chairman *Professor Eric Roberts*

Session 6 – Chairman *Dr Arjoon Sudhoo*

Session 7 – Chairman *Mr Alain Noël*

Posters

FOREWORD 1999

The Food and Agricultural Research Council funded the fourth Annual Meeting of Agricultural Scientists of Mauritius (AMAS), which started in 1995 as part of the World Bank assisted Agricultural Management Services Project.

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 were encouraged once again to present papers at this meeting. As a result thirty 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 Professor Jay Baguant, Pro Vice-Chancellor of the University of Mauritius. It is worth mentionning also that three papers from Fruit Fly Regional Programme for the Indian Ocean were presented.

I am 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.

Jagadish Mawrahkan

Acting Director General

WELCOMING ADDRESS 1999

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 am pleased to welcome you to the fourth annual meeting of agricultural scientists (AMAS) organised by the Food and Agricultural Research Council, in partnership with the Albion Fisheries Research Centre, the Agricultural Research and Extension Unit, the Agricultural Services, the Mauritius Sugar Industry Research Institute and the University of Mauritius.

This gathering continues the tradition of providing a good opportunity for our agricultural scientists meeting one another and sharing their research results with the agricultural community. We have had another good response to the call for papers. Even if the quality of papers has improved, a selection had nonetheless to be made. I wish to thank members of the refereeing team who have helped us in the selection process.

While it remains our objective to continually raise the standard of papers presented at future conferences. We are examining alternative ways of restructuring the AMAS to better serve Agriculture and Science, the agricultural community and the Country, not to mention the Region. Thirty papers will be presented during our two-day meeting.

I am pleased to welcome among us Professor Eric Roberts who has been closely associated with the development of the FARC and AREU.

A special word of thanks to the Organising Committee which has spared no effort to make this conference a success.

Our keynote address this year is dedicated to Professor Jay Baguant, whose memory we wish to honour for his contribution to scientific research. The subject of this address "Agriculture and Energy" pays tribute to his efforts. It is with great pleasure that I welcome Dr TR Bott, Senior Lecturer, School of Engineering, University of Birmingham, to deliver this lecture. I am grateful that he has accepted our invitation.

Minister, Ladies and Gentlemen, I thank you for your presence at this meeting.

MINISTER'S ADDRESS 1999

Dr The Honourable *Arvin Boolell*

Minister of Agriculture, Food Technology and Natural Resources

Distinguished Guests
Ladies and Gentlemen

I am pleased to yet again be invited to make a brief address on the occasion of this 4th Annual meeting of Agricultural Scientists today. May I also mention my appreciation to the organisers for this initiative, which has now become an annual feature, having attained cruising speed.

Could I begin by setting the scene for our agricultural and food systems, and the formidable challenge at hand particularly for the heterogeneous, non-sugar sector: how are we to make this agriculture into a modernised, professionally-oriented, economically viable and sustainable one, against a background of scarcity in most of the needed resources, while also having to satisfy the ever-increasing standards, norms and exigencies of a more sophisticated consumer? And in an increasingly globalised, competitive and market-oriented context which is narrowing, direct intervention or protectionist possibilities of national governments.

In essence, our agriculture, natural resources and food systems are being subjected to various aspects of a fast pace of change and risk - both domestic and global - which have serious implications for agricultural policy, and which invariably means an intensification of the need for research and a greater output from a more effective research system.

We have to develop a capability to manage this change and risk, through appropriate and prompt policy responses. And we expect research to support this continuing challenge, by clarifying and identifying whilst also helping the implementation of the policy choices, in conformity with the Government's aims and objectives in relation to national development. Public funding in research, to which we are committed in the context of a non-market intervention strategy, will however be increasingly geared towards investigating methods to attain our broad policy objectives. 1 shall come back on this shortly.

Our research system should also be able to cope with the requirements of all producer categories big and small and be responsive to the needs of industry, the public sector and the consumer. Our researchers should devote much more time to getting to understand the more vulnerable groups, i.e. the small producers, and their problems, working with them to find solutions, and be a catalyst for change while being at the forefront in developing new technologies and programmes And then to collaborate with extension officers to determine methods of disseminating results of such research: that is, a more pronounced approach to Farming Systems Research and Extension. It is also crucial that the accumulated experience of our farmers should constitute the starting point of a systematic research programme. We cannot afford to discard the impressive collection of empirical examples gathered around the world that demonstrates the breadth of farmers' knowledge and skills. We must be able to integrate these to build synergy into agricultural research. I am happy to note that all this is being given due consideration by our research institutions for some years now.

It is laudable to organise such annual meetings and more widely diffuse and publish research findings. But are we keeping track of the "Next steps To Do' we have a monitoring or tracer system that can inform us of the practical translation, if any, of at least some of the more "ripe" output of research?. Some of those ideas, technologies, techniques, products, processes etc. that would have been mentioned in the past years and their fate?. Research results should not only be seen to be presented or published which may ran the risk of being qualified as mere rhetoric - but quite a few of them of an applied nature should also be seen to be delivered and translated into practice.

The challenge is to make the production technologies, techniques and processes, products, ideas - the output of research - applicable to the varying needs and resources of agricultural producers and other clientele.

An effective research system is also critical in the sense that it must enlighten Government to cope with these challenges. It is our policy to strengthen linkages between research and agricultural policy. My Ministry and myself as Minister need to be provided with policy advice and decision support on a wide range of issues, and policy advice is built on a foundation of robust data. We believe that Science and Research should also be the purveyors of such data and information to assist policy development. We may even in the near future be prepared to contract out such strategic or policy-oriented Research, sometimes also dubbed as "Operational Research", which unfortunately has been lacking so far.

I can very briefly cite a few of the priority areas and themes that could constitute the planks of such research endeavours.

Agricultural Security: ranging from border control, pest and disease surveillance systems and their tools, development of diagnostic capabilities, the expanding need for data around the requirement for complying with international protocols, e.g.. WTO SPS, etc. and the impact of climatic changes. No need to reiterate the sorry state caused by the lingering drought -we need to develop a Meteorological Surveillance and forecast system, again for a better preparedness - and the input of Professor LOMAS is appreciated in this context. Noteworthy also is the Agrochemical study by MSIRI with the help of Australian Scientists; and the monitoring of pesticide residues by my Ministry, whose results shall be better diffused on a regular basis in the near future.

Facilitating Market Access: Market intelligence information for a better preparedness - to assist in developing and implementing policies to facilitate access of our products to overseas markets - and domestic ones as well - e.g. by decreasing trade distortions and minimising potential trade barriers that could be raised against our products, by analysis and modelling of scenarios related to trade liberalisation; by appraisal of the regional dimension and opportunities for our agriculture, etc.

Facilitating Resource Management: to provide information to assist in developing and implementing policies on biophysical factors which influence sustainable agricultural development e.g. food safety a complicated, multi-agency issue, a priority objective to be attained in the area of food technology that extends from the plough or fishing boat to the plate with increasing focus on post-harvest technologies and processes; environmental impact of agricultural practices, etc. Activities here would include development of environmental indicators e.g. on soil, water and air qualities; biodiversity, energy use, etc.

Emerging Technologies: There is an explosion of new technologies and techniques, and it is important to keep track of these and their implications. This should not be difficult with a parallel explosion in communication and information technologies. The next decade in fact will be that of the biotechnologies, where particular attention and care should be focussed on the GMO's (genetically modified organisms), the cause of so much controversy these days. National guidelines are urgently needed, we have to draw up bio safety measures and to monitor changes in biodiversity, demand transparency and consider the social, economic and ethical dimensions. My Ministry is already embarked on several initiatives in this respect. A committee is reviewing the Plants Act for amendment soon; another committee on Food Safety has been set up, grouping all the parties involved; and I am also proposing to set up a "Committee on Ethics" to look at the ethical issue. What I would request from the Scientific and Research community in this context is rigour in their research undertakings. From what's happening in the developed World in the domain of new technologies and food safety, we are already witnessing what a disastrous combination political nervousness is with consumer ignorance. The outcome is delays and distortions in decision-making, not to mention gridlock, and we would not want unreliable research or the merest scintilla of doubt to make the combination into an explosive one.

Promotion of Industry and rural development: Due consideration should be given here to the broader socio-economic environment as it affects the Agricultural and Food Systems: e.g. impact of the legislative environment; effectiveness of Government interventions and schemes, etc.

Long-term, Perspective Studies: which are important to help Government in planning and policy-making. Needed here are rigorous analyses of policy and strategic issues. I understand that the FARC is defining the focus of several such studies to, be undertaken in the context of higher-degree programmes.

We shall give all the support necessary to this innovative scheme.

And finally 1 would also wish that our research organisations come up with what is denominated as Outreach Programmes; which deal with the provision of technical advice and support to key policymakers, where recommendations are made on policy options and strategies that would best address the country's development concerns. Very few examples of such initiatives exist, and that also mainly on request. We want our research organisations to be pro-active here.

Ladies and Gentlemen,

I feel happy that an illustrious son of the soil, who most unfortunately left us some time back, is to be honoured shortly by a keynote address on a subject that was so dear to him. Professor J Baguant epitomised the versatility and rigour and dedication that I've been speaking about, and I can only wish that our researchers be inspired by his shining example.

Finally, let me also hope that your output and deliberations will guide us in improving our agricultural policies in the national interest. I wish you a successful meeting.

I have now the pleasure to declare this meeting open.

PROFESSOR JAY BAGUANT MEMORIAL LECTURE
KEYNOTE ADDRESS 1999

AGRICULTURE AND ENERGY

TR Bott

University of Birmingham

The *curriculum vitae* of Professor Baguant demonstrates, among many activities, two important aspects of his life's work that have a direct bearing on the economy of Mauritius. They are: the development of the sugar industry through his teaching and research, and the wider implications of energy usage and policy. It is fitting in this memorial lecture therefore, to review the relationship between agriculture and energy, and some of the implications globally and for Mauritius in particular.

ABSTRACT

The invention of farming, estimated to be about 8000 years ago, has had a major influence on the elaboration of human activities. The rapid industrial development initiated by the invention of the steam engine, has increased the demand for energy, largely fossil fuels. In order to conserve energy there is a need to investigate urgently renewable sources. Agriculture is in the unique position to provide renewable energy, not only by the use of waste products, but also to grow speciality crops with the object of energy production. A number of different processes are available for this purpose, but perhaps the most convenient is raising steam for power generation, by the combustion of suitable feedstocks.

Combustion produces CO_2 a "greenhouse gas" that is associated with the phenomenon of global warming, but by careful analysis of the problem, the net contribution of CO_2 to the atmosphere can be reduced or even eliminated. There are other technical difficulties that have to be faced, not least the deposition of mineral matter on the heat transfer surfaces. An enviromnentally friendly scheme proposed by (Beeharry 1999) for electrical power production from sugar cane residues, is an excellent example of how agriculture can not only provide food for the growing population but at the same time, make a significant contribution to energy provision.

Keywords : agriculture, energy, renewable energy, electrical power, sugar cane residues, bioenergy energy farming.

INTRODUCTION

In many parts of the world agriculture is in a depressed state and in crisis. Current newspaper articles recount the difficulties encountered by the farming industry. Headlines such as: "Farmers' tough row to hoe" (Anon 1999a) and 'Why Britain's farmers are making a loss on nearly everything they grow" (Anon 1999b) appear from time to time. All aspects of agriculture seem to be affected.

There are concerns too about energy resources in the future, and this is often coupled with anxieties regarding pollution of the environment, the threat of climate change with consequent disasters due to global warming.

Perhaps all these aspects provide an opportunity for agriculture to take on a new dimension, to become an energy supplier as well as a food producer. By careful development and assessment, a contribution of energy to world requirements may be made without detrimental consequences for the environment. Furthermore energy produced by agriculture is a renewable resource.

HISTORICAL BACKGROUND

Of all the innovations created by the human species, the most far reaching and influential was the invention of agriculture. A close second was industrialisation, which began to accelerate in the late eighteenth century. The former has allowed civilisations to be established and the latter to power manufacturing processes with profound effect in all aspects of life.

For millions of years till about 8000 years ago humankind existed as hunter-gatherers living off the land; this necessitated continual movement from place to place as the available food was consumed. The natural development of this existence was the slash and burn technique, where the land was cleared and the debris burnt to give the opportunity to plant primitive crops for a season or two till the land became impoverished. It was then time to move on, the land being left to recover by natural processes.

The practice is still in evidence today in remote parts of the world, but perhaps with some modifications. The Baduy tribe in Western Java for instance, plant a special species of tree with their rice, after the rice has been gathered the trees are left to mature, replenishing the soil in four years. Modern adaptation of the technique of slash and burn, using mechanical methods, is also used in some parts of the world for example in South America, often with devastating effect on the local environment and the habitat of the wild life.

The seemingly simple discovery of planting, cultivating and harvesting food, laid the groundwork for civilisation. The tempo of human life accelerated, agriculture rapidly developed based on techniques that had appeared among certain hunter-gatherers living in favoured places. It encouraged permanent settlements in place of nomadic wanderings, inspired the invention of new tools and techniques, and stimulated the elaboration of arts and crafts. It triggered an explosive increase in population, encouraging not only larger families, but also large complex societies, which in turn fostered government, trade and communication among great numbers of people.

There have been many advances of course along the way; cutting tools and the invention of the plough for instance. Light ploughs were used by Greeks and Romans (a plough is depicted on a Greek cup attributed to the sixth century B.C (Derry and Williams 1960). Before the eighteenth century, all seeds were sown by hand and usually scattered at random. Irrigation was also important, particularly in the more and regions of the Middle East, and irrigation ducts filled naturally or by the effort of man or beast, were used to great advantage. A picture from a tomb at Thebes, dating from 1500 B.C. shows a manually operated irrigation device watering date palms. In 1701, mechanisation entered farming when Jethro Tull perfected a drill which sowed in rows, so that fewer seeds were wasted, and it was easier to weed and interplant. Modern seed drills are still based in the same kind of principle (Anon 1999c). The introduction of crops that were not native to the particular part of the world, such as the potato into Europe added to the diversity of farming. The development by plant geneticists like Sir Ralph Riley, of disease resistant and drought tolerant wheat, and high yield varieties that vastly increased throughout in Britain in the 1970s (Anon 1999d), have made significant contributions to agriculture.

Advances in technology such as modern agricultural equipment on tractors and combine harvesters able to measure a field's yield, combined with information from orbiting satellites, can indicate the productivity of different parts of the field. As a result action can be taken to control fertiliser application to improve economics and reduce the detrimental effects on the environment (Anon 1999e).

The development of technology, itself made possible by the invention of agriculture, has therefore had its own impact on farming. Until the accelerated development of industry generally referred to as the "industrial revolution", in the late eighteenth early nineteenth century the energy input in agriculture for activities like sowing, irrigation and reaping came from man or beast that in turn was derived from the crops that they had produced.

The industrialisation which gathered pace about 250 years ago, was essentially based on cheap fuel in the form of coal and the abundance of cheap labour. The invention of the steam engine by Newcomen and much developed by Watt, was the source of power to drive manufacturing processes. It was not long before agriculture began to benefit from the technological advances of industrialisation. Steam engines used to power machines in factories were adapted to drive agricultural equipment such as threshing machines.

The internal combustion engine, itself based on the development of liquid fuels, appeared about 1900, but its enormous influence was not felt till well into the twentieth century. The principal effect on agriculture has been the replacement of human and animal labour in agriculture. Ploughing, reaping and threshing, are prime examples, but the internal combustion engine has been put to work in pumping for irrigation, transporting crops and general work on the farm.

The widespread availability of electrical power, originally derived from the combustion of coal but more recently of petroleum and natural gas, and the contribution of nuclear power, hydroelectric schemes and wind energy, has also had an impact not only on industry, but the quality of life for much of the world's population.

As part of the rapid advance in industrialisation the processing and manufacture of chemicals, was made possible by the availability of large vessels, and other equipment. An extremely large influence came in the shape of artificial fertilisers - no longer did the farmer have to rely on natural sources of plant nutrients. The large-scale production of steel for instance, produced a by-product of basic slag, a combination of limestone and phosphorus that was a valuable fertiliser. In the early part of the twentieth century chemicals were manufactured to provide fertilisers. The era became known as the "Green Revolution" and contributed greatly to crop productivity. Further developments in the shape of sophisticated chemical herbicides and pesticides soon followed to improve yields. All these chemical processes are energy intensive. There are proposals to introduce a pesticide tax in the U.K. (Brown 1999), to reduce the fossil fuel emissions but the current world-wide rate of pesticide application is regarded as unsustainable in the long term (Scmidt- Bleck and Marchal 1993). Losses in crop yield due to pest damage alone worldwide are of the order of many millions of pounds per annum. The need for control is clear. An alternative to chemical addition is the development of natural predators.

It may be seen by this brief examination of history, that over the last century there has been a rapid increase in the dependency of agriculture on external sources of energy. The use of this energy has made a tremendous contribution to the supply and quality of food.

Questions concerning the effect on the environment of fuel combustion and the depletion of the world's energy resources, through all aspects of human activity are gaining strength. An intriguing issue is whether or not it is possible to use agriculture to reduce at least some, of the imbalance.

THE OPPORTUNITIES

The importance of biomass in the energy field has been highlighted by the European Commission (Anon 1997) The campaign will run for five years (1999-2003) and includes: 104 MW of combined heat and power biomass installations, 106 dwellings heated by biomass, 103 MW biogas installations and 5×10^6 tonnes of liquid bio fuels.

A number of different options are possible to allow agriculture to be involved in energy production; some are based on existing industrial operations but adapted, others use modifications of technologies originally in the fuel industry or from the disposal of wastes.

AGRICULTURAL WASTES

Agricultural wastes may be defined (Varani and Burford 1977) as:

> The residue from animal husbandry operations, principally manure. Much of the material is currently used, in its traditional manner as an addition to agricultural croplands. With the move in many countries, towards so called organic farming, employing traditional methods, the availability of these wastes is not likely to be significant for purposes other than as fertilisers.
> Food processing wastes represent a wide range of materials from residues from crop preparation after harvesting at the farm e.g. vegetable stems and unsaleable products to residues resulting

from factory processing immediately prior to marketing e.g. husks and shells, fruit skins and peel.

Crop residue left in fields after harvesting, this could include materials such as straw or sugar cane leaves.

SPECIALITY CROPS OR BIOMASS

Crops surplus to the primary purpose of providing food, may be grown to serve the energy market. A good example is the fermentation of sugar to produce ethanol as a fuel for internal combustion engines. At the same time it is becoming increasingly economic to grow crops specially designed to serve the energy market. The philosophy is similar to that adapted by the paper industry to use managed forests for virgin paper manufacture (Anon 1999e) There is considerable scope for this kind of approach to be more widely adopted with energy as the principal product rather than to supply food. The potential to use genetically modified crops to make them more amenable to the energy producing process adopted, is certainly a distinct possibility in the future. Highfield (1999) reports the development of genetically modified aspen trees that can grow twice as quickly as normal, with a lignin content reduced by half. As a result the use of harsh chemical treatments necessary to remove the lignin from the wood pulp, prior to conversion to paper is reduced. Such developments could have a future economical impact on the energy industry as well as on paper making for which the work was initiated. A major hurdle in this respect, is the resistance of some sections of society that are opposed to the widespread introduction of genetically modified crops, e.g. Green peace and the Soil Society in the U.K.

There are, in addition to what might be termed ethical objections to agricultural energy production, and these are concerned with the fundamentals of husbandry. Some of the objections have been described by Bungay and Ward (1977). For the economic production of speciality crops (whatever that might be e.g. wood, or switch grass) for the provision of energy, the whole plant above the ground would be collected. Whole plant processing differs greatly from the usual practice in food cropping and forestry, where trimmings and residues are generally left to rot. Some enrichment of the soil is the result.

A further challenge is that agriculture cannot merely take from the land; large amounts of fertiliser are required. The need for phosphorus and nitrogen particularly, could represent a difficult barrier to overcome. Recycling of nitrogen or phosphorus to soil, e.g. wastes from the biomass to fuel (energy) conversion process must be considered. Ash from a thermal conversion process could present difficulties if the constituents are not in a suitable form e.g. poor solubility. Recycle is not likely to be acceptable if most of it has gone, wasted or blown away, before it can be absorbed by the growing plants. On the other hand, in conventional agriculture much of the added fertiliser can also be lost through run off or depth percolation. Some of these issues will be discussed later in connection with the application of an energy process utilising residues.

UNIT OPERATIONS IN BIOENERGY PRODUCTION

All or some of the following unit operations could be involved in energy production:

1. Site preparation
2. Sowing or planting
3. Cultivation
4. Cutting and harvesting
5. Collection and transportation
6. Shredding or grinding
7. Conversion
8. Final waste disposal

Different types of biomass, and the technology adopted to convert the chemical energy content in the plant to applicable energy, can dispense with certain operations.

ENERGY PRODUCING PROCESSES

A number of different processes some have already been mentioned, are available for the conversion of biomass into fuel or energy, briefly they include:

1. Anaerobic digestion : Digestion anaerobically involves the production of methane gas, which may be used as an onsite fuel or pipeline gas. Enzymatic hydrolysis of some feedstocks, e.g. cellulose containing material, may render the biomass more amenable to fermentation and increase yields.

2. Fermentation : Fermentation particularly of sugars can produce ethanol, acetone, butanol, and a number of other liquid organic chemicals, normally derived from petroleum that may be regarded as liquid fuels.

3. Combustion : In combustion processes the combustible content of the biomass is burnt and the heat generated in the flue gases is used to produce steam. The energy content of the steam is then used as a source of heat energy in factory processing, or more generally to produce electricity by expansion through a condensing turbine and associated generator. A major environmental problem associated with combustion is the question of emissions particularly "greenhouse gases" such as $C0_2$. Combustion may be divided into two areas:

   a. Combustion of the solid fuel on some sort of grate (fixed or moving), i.e. similar to the traditional method of raising steam or incinerating waste.

   b. A more recent technology is to use a fluidised bed, where a particulate bed of some inert solid is suspended by the upward flow of gases (air plus flue gases), into which the material to be burnt is injected. The technique has a number of advantages but principally it provides for a more uniform combustion process and better control. Ash disposal is facilitated. A full discussion of biomass combustion in fluidised beds is discussed in Bott (1993). Combustion will be further discussed later

4. Gasification : A process similar to the steam/oxygen process for gasification of coal can be used to produce a fuel gas. The biomass suitably sized by shredding or grinding, is fed into a pressure vessel, where it travels counter current to a synthesis gas produced at a lower level by steam/oxygen injection into the falling char residue from the upper vessel. A gas containing relatively high methane content leaves the top of the upper vessel.

5. Pyrolysis : High temperature heating of biomass vaporises volatile matter, which consists essentially of low molecular weight organic chemicals, including light oils that may be used as a source of energy. There are a number of different ways in which the biomass heating may be accomplished. Of considerable influence on the process to be adapted is the quality of the biomass, coupled with the need to maximise the yield for low heat demands and how that heat is generated.

The choice of technology for the production of fuel or energy from biomass, depends on many factors not least the quality of the intended feed stock, its availability, and the location of the plant. The latter not only involves the introduction of biomass in to the processing plant and hence the form in which the biomass is available but also the energy requirements e.g. whether electricity production, or the provision of liquid or gaseous fuel.

In general terms combustion technology to produce electricity is likely to be the most acceptable. The product electricity has widespread applicability and combustion technology is well established and well understood. In comparison with many of the other technologies it is relatively simple and straightforward. It does not require pressure operation, imported reactants like oxygen or microorganisms, complex separation technology or aseptic control as with fermentation. Furthermore, combustion does reduce the solid fuel to manageable proportions (the ash), thereby eliminating the need to dispose of residues that might require further processing. By careful analysis it is possible to produce energy economically and at the same time, take into account all aspects of environmental protection.

COMBUSTION OF BIOMASS IN MORE DETAIL

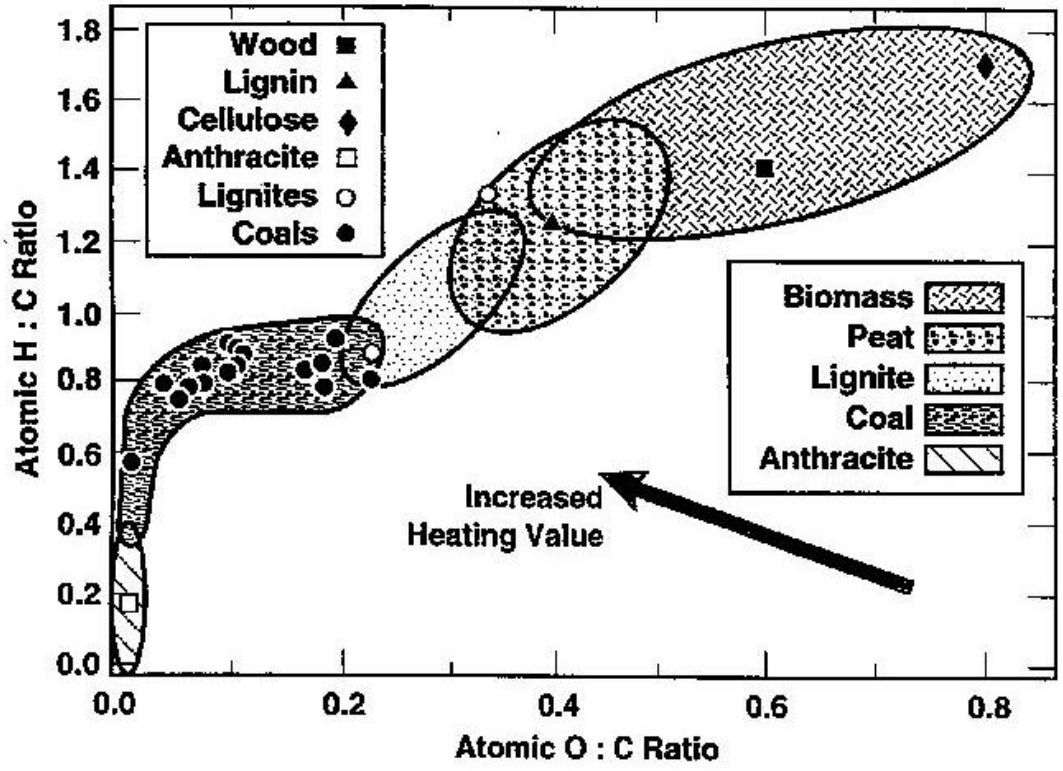
Materials that are used in combustion for steam raising have been classified into three principal groups (Baxter et al 1996)

1. Herbaceous Fuels e.g. rice straw, wheat straw and switch grass
2. Ligneous Fuels e.g. almond shells, pistachio shells, olive pits, almond hulls
3. Wood and commercially e.g. wood and almond shell blends, wheat straw blends, Wood based fuels non-recyclable paper.

Fuel characteristics

Wood and wood derived products are currently the most commonly used biomass fuels, partly at least, because wood has been used as a fuel for thousands of years. It has arelatively high calorific value and low moisture content. The relationship between biomass and other fuels in terms of hydrogen-carbon, and oxygen-carbon ratios is presented in **Figure 1** (Baxter et al 1996) The higher hydrogen and oxygen compared to carbon content is shown on the figure, it is the carbon that contributes the greatest calorific value to the fuel.

Figure 1. Solid fuels and their chemical composition



In consideration of the combustion of a particular biomass a number of interacting factors have to be taken into account, in order to facilitate operation and maximise the energy yield. A number are related to the engineering of the boiler plant, others are related to the fuel.

Process requirements

Important considerations include feed preparation, which is likely to involve one or more of cutting, chopping, shredding and grinding operations. The choice will depend on the physical characteristics of the fuel. In some instances, e.g. straw combustion, the straw may be burnt in bales (as produced in the field) or after shredding, A major problem in the combustion of tightly packed bales is the difficulty of maintaining even combustion.

In large commercial operations size reduction, although incurring an added operating cost, is likely to give rise to fewer operating problems, and provide a steady heat output.

The moisture content of the biomass has implications for the efficiency of the combustion process. Moisture contained in the fuel will vaporise; the necessary latent heat of vaporisation being taken from the heat produced by combustion i.e. reducing the heat available for steam raising. Furthermore, high levels of moisture content will affect the incineration process itself. Indeed some designs of boiler plant cannot operate properly if the moisture content is too high. Fluidised bed combustors can in general, tolerate wetter fuels than those burnt on a grate.

The incombustible mineral matter originally part of the biomass structure, remains after the combustible components, comprising essentially of carbon and hydrogen have been converted to C02 and H20, will have to be removed from the boiler as ash. Efficient removal is essential to maintain the combustion characteristics of the fuel in the boiler, and to facilitate plant operation.

Fouling of heat transfer surfaces

Although effective ash removal may be achieved it is inevitable that some of the mineral matter originally in the biomass will go forward as particles with the flue gases. This particulate matter represents a serious hazard to the recovery of heat from the flue gases, since it tends to foul the heat transfer surfaces. The deposit acts as an insulating layer, reducing the heat transfer for a given temperature driving force between the flue gases and the saturated steam temperature in the boiler. The extent of the fouling will depend on the chemical composition of the materials found in the fuel. In most boiler plant, facilities are included in the design, to remove deposits as they accumulate. A common technique is to use traversing jets of air or steam to "knock" the deposit from the heat transfer surfaces. Acoustic vibrations may also be employed. The problem is not so serious in fluidised bed boilers where the inert particles making up the bed, tend to arrest the ash particles. The ash at the temperature of the flue gas, depending on its composition, may be may be molten so that it is less amenable to removal. Accumulation of molten material is often referred to as "slagging". Furthermore, the sticky mass also may trap solid particles adding to fouling problems.

Baxter et al (1996) have made an extensive study of the fouling propensity of biomass fuels. Herbaceous plants contain silicon and potassium as their principal ash forming constituents. Additionally they contain relatively high levels of chlorine. Severe fouling problems at high and moderate combustion temperatures are likely, due to the presence of these elements. The problems arise due to:

1. The formation of alkali silicates that soften or melt at relatively low temperatures.
2. The reaction with sulphur to form alkali sulphates.

It is clear that the presence of alkali in the ash will have a profound influence on the fouling or slagging process. Potassium is the dominant alkali element that is present in most biomass fuels. It imparts high mobility to the ash. Many agricultural by-products also contain high potassium levels, but some woods contain far less overall, with a possible reduction factor of 40 compared to say, high ash straws.

Calcium reacts with sulphur in a similar way to potassium, but the mobility of the ash is much less than that associated with potassium, so that calcium deposits are much more favourable to sustained combustor operation than ashes containing high potassium levels.

Chlorine is also an element that influences ash properties. Potassium chloride is among the most stable high temperature, gas phase, alkali containing species. In the absence of chlorine, alkali hydroxides represent the principal gas phase species in oxidising environments in the presence of water vapour (combustion gases).

CONSTRAINTS ON ENERGY FARMING

Some of the technical difficulties associated with the production of crops have already been alluded to, but there are others that are concerned with economics and the wider issues of acceptability. There is interaction between these constraints and the technical difficulties.

The concept of producing energy from biomass stands or falls on economics. There are three important elements to take into consideration:

1. The energy needed to produce the crops (e.g. soil preparation, fertilisers, pesticides) and to collect, prepare the biomass, and to deal with residues in relation to the energy produced i.e. the net energy available.
2. The proximity of the purchasers of the energy produced i.e. distribution costs.
3. Labour costs.

In order to improve economics the whole plant must be utilised, i.e. stems, leaves and roots. Attendant difficulties are:

1. Particularly in the case of trees, soil erosion by rain and wind may become a problem. Roots bind the soil, and trees act as wind breaks.
2. The removal of the total plant, i.e. none is left in the soil to rot and replenish plant nutrients. The immediate answer might be to add fertilisers but this procedure adds to the cost, and there is an energy content in the added chemicals. The return of residues, ash from combustion for instance, is a possibility but the chemical transformations that have taken place during processing (i.e. incineration) may produce compounds with poor solubility. Removal of roots may be difficult and expensive to achieve.

Environmental issues must be considered. If combustion is used to produce electricity via steam generation, the discharge of $C0_2$ to the atmosphere must be taken into account. Crop metabolism involves the conversion of $C0_2$ to plant material. In theory the net contribution to global warming is zero since the equivalent $C0_2$ produced in the process will be fixed in the next growing crop of equal mass. There may be other environmental factors peculiar to the location.

Governmental fiscal policy may be a factor for consideration. Tax incentives for instance to encourage environmentally friendly processes and the development of renewable energy may improve the economics. Capital grants may also aid the establishment of viable biomass to energy schemes. A concern in this respect is that the policy may change with a change of Government, that could seriously affect the economics of the enterprise.

Before the introduction of a commercial scale energy from biomass processes, careful analysis of all the interacting factors is required, to demonstrate its potential viability.

ENERGY FROM BIOMASS IN MAURITIUS

Mauritius is ideally placed to benefit from using biomass to produce energy. The land is very suitable for agriculture and the population is well served with its electrical power distribution system, facilitated by the relatively high population density (about 560/km^2). Much of the energy for conversion to power however has to be imported as fuel e.g diesel oil.

The principal agricultural activity in Mauritius is the production of cane sugar. Already part of that crop, in the shape of bagasse (the solid residue from sugar extraction) is incinerated to produce steam for process heating and the generation of electric power. Surplus power is available for feeding into the national grid. Despite the seasonal nature of sugar production bagasse from the sugar industry is used to generate about 10% of the current electricity demand in Mauritius. The fouling problems associated with the combustion of sugar cane bagasse are very much less than those associated with straw and

other herbaceous crops. Although sugar cane bagasse is derived from a high potassium and high silica bearing crop, both potassium and chlorine are substantially leached from the fuel in the process of extracting the sugar.

In an excellent and searching study, (Beeharry 1999) has demonstrated that further developments in the use of sugar cane residuals for energy production is technically feasible. The analysis and assessment he has made revolves around extending the biomass available for energy production by including cane tops and leaves and cane trash in the process. The total biomass available, based on the 50% moisture content of bagasse, is almost doubled by utilising these additional components. The ash content of the combined biofuel is around 5.5-6.5% i.e. relatively low.

Ultimate analysis of total sugarcane biomass (bagasse, cane tops and leaves, and trash) revealed that the atomic oxygen to carbon, and the atomic hydrogen to carbon ratios were similar to wood (**Figure 1**) The combustion of cane tops, leaves and trash, with the bagasse is likely to lead to deposit formulation on the heat transfer surfaces, due to the mineral constituents of these components, i.e. similar to straw.

Beeharry (1999) has examined three new options as alternatives to the present system of bagasse combustion to utilise sugar cane crop residues for electrical power generation. They include:

1. The use of whole cane where the cane stalks are harvested together with the cane tops and leaves. The process of sugar extraction leaches out at the elements that would be responsible for fouling in the combustor.
2. The cane tops, leaves and trash are collected and baled. They are shredded and washed to remove the potential fouling species, dewatered and mixed with the bagasse before combustion.
3. A composted bagasse option involves producing compost from a mixture of moist bagasse and filter cake, which is then used to improve the soil quality by replacing some of the chemical fertilisers necessary to maintain productivity. By mixing the ash generated with the final compost it is possible to avoid disposal problems and to help close the nutrient cycle.

The results of the analysis performed by indicate that energy from sugar cane biomass requires a fossil fuel subsidy. Upstream energy required to make fertilisers, and pesticides accounts for more than 75% of the total while the remaining 25% of the fuel input is due to machinery and transport. It is not possible in this paper to give details on these options but some comments may be made. In current practice for every kWh of electricity based on the allocated upstream fossil fuels, 5.90 kWh of electricity is produced. For options 1, 2 and 3 the equivalent data are 6.64, 6.59 and 7.36. Clearly option 3 has a higher return in terms of energy. Some of further salient features are given in **Table 1**. Data on current practice for energy from bagasse are also included.

Table 1 Comparison of options and the current practice

Option	Carbon closure* %	Cane mass recycled to field %	Increase in emissions compared to current practice %
1	97	48	118
2	96	31	213
3	98	76	0
Current practice	99	68	0

* Carbon closure may be defined as the $C0^2$ taken up by the growing plants compared to the $C0^2$ produced in the combustion process.

These data suggest that in all the options the carbon closure is good i.e. > 96%. Enhanced electricity output is likely to cause soil impoverishment that will certainly require inorganic fertiliser to maintain productivity, but the amount required is lower with IS. Option 3. Options I and 2, particularly Option 2, produce higher emissions than current practice. On the basis of a preliminary review it would appear Option 3 is worthy of further investigation.

CONCLUDING REMARKS

In many respects the invention of agriculture has through the ages, directly and indirectly led to an ever increasing demand for energy in both the industrial and domestic sectors, particularly over the last hundred years. As a result there is concern regarding the depletion of fossil fuels, and for the problems that could arise due to "global warming".

The discussion reveals that there is considerable scope for agriculture to develop in the energy business. Not only does this diversify the industry but it has environmental advantages, in terms of renewable energy and emissions. It would not be possible of course for agriculture to satisfy the world's increasing needs for energy, but by careful application of known technologies and thoughtful development, it is likely that the industry could make a significant contribution to energy in the next century.

Life cycle assessment - the idea of following a product's (e.g. energy) entire supply chain is already established, but two new ideas are being considered: industrial ecology and sustainable development (Clift 1999). These are very relevant to extending the relationship between agriculture and energy.

The utilisation of sugar cane residues for electricity generation demonstrates the advantages that are possible. Because of the tradition of using bagasse for power generation in Mauritius, and the knowledge this has produced, the country is in a good position to develop the technology of biomass to energy and thereby improve the economic strength of the country, and at the same time make a valuable contribution to environmental conservation.

REFERENCES

ANON. 1997. *Strategy and Action Plan, Energy for the future: Renewable Sources of Energy*. European Commission Com. (97), 599, 23rd November 1997.

ANON. 1999a. *USA Today* Newspaper, U.S.A. 24th August 1999

ANON. 1999b. *The Independent Newspaper* U.K. 28th August 1999

ANON. 1999c. *Farmers' Tale*. British Philatelic Bureau, 1999.

ANON. 1999d. Obituary of Sir Ralph Riley. *The Daily Telegraph*, London ,September 1999.

ANON. 1999e. Forest Management - Can You See the Wood for the Trees. News Review. *The Newsprint and Newspaper Industry Environmental Group. Issue 3* Spring, 1999.

BAXTER LL et al. 1996. *The Behaviour of Inorganic Material in Biomass , Fired Power Boilers, Field and Laboratory Experiences*. Vol. II of Alkali Deposits Found in Biomass Power Plants, U.S. Department of Energy 1996.

BEEHARRY RP. 1999. "Biofoul Characterisation and Life Cycle Assessment of Sugarcane Bioenergy Systems" Ph.D. Thesis, University of Mauritius, 1999.

BOTT TR ed. 1993. *Report on Fluidised Bed Technology as Applied to Waste Incineration*. Inst. Waste Management 1993.

BROWN D. 1999. Green Taxes to Curb Pesticide use will Devastate Farmers. *Daily Telegraph* Newspaper, U.K. 26th July 1999.

BUNGAY HR and WARD RF. 1977. Fuels and Chemicals from Crops *in* ANDERSON LL and TILLMAN DA eds *Fuels from Waste*, Academic Press, New York 1977.

CLIFT R. 1999. The Great Challenge - a Sustainable Future. *Newsline*, p.6, E.P.S.R.C. September 1999. AGEN/TRB

DERRY TK and WILLIAMS TI. 1960. *A Short History of Technology*. Oxford University Press, Oxford 1960.

HIGHFIELD R. 1999. Professor's Trees Can Cut Use of Chemicals, *Daily Tele*graph Newspaper, U.K. 27th July 1999.

LEONARD JN. 1974. The First Farmers, *Time Life International*. 1974.

SCHMIDT-BLECK F and MARCHAL MM. 1993. *Reg. Toxicol. Pharmacol* 17, 262-281 1993.

VARANI FT and BURFORD JJ. 1977. Conversion of Feedlot Wastes to Pipeline Gas *in* ANDERSON LL and TILLMAN DA. eds *Fuels and Waste*. Academic Press, New York, 1977.

APPLICATIONS OF THE GLOBAL POSITIONING SYSTEM IN THE MAURITIAN SUGAR INDUSTRY

I Jhoty

Mauritius Sugar Industry Research Institute

ABSTRACT

The applications of the Global Positioning System (GPS) technology in the mauritian sugar industry are reviewed. It is found to be an appropriate tool in the timely and rapid production of large scale topographic and 2m contour maps for land planning, siting of irrigation systems, deriving digital elevation models, establishing ground reference points and the collection of environmental location data for GIS. The prospects of further applications are discussed in relation to precision farming, orthoimages and positional data for utilities.

Keywords : sugar industry, contour maps, land planning, Global Positioning System, GPS, Geographic Information System, GIS, precision farming, Mauritius.

INTRODUCTION

In the context of the rationalization of the sugar industry with a view to increasing productivity, the collection and compilation of precise location data are important issues. With the introduction of more efficient irrigation systems and mechanization of cultural practices, one of the basic requirements is the production of large scale (1:2500) topographic and contour maps. These maps are particularly needed to show certain detailed ground features and height differences of 1 or 2 m for determining layout of fields, roads, drainage lines, cane row directions and erosion control measures. The application of the geographical information system (GIS) in the industry on the other hand relies on these large scale maps for the compilation of digital cartographic databases and digital terrain modelling (Jhoty 1995). Referenced positional data of environmental features other than from maps are also other requirements in the GIS. The production of large-scale maps has not kept pace with development of the various sectors of the economy in the demand for these maps. About 53 % of the country is covered by large-scale maps, which are considered outdated in terms of many cartographic features. It is not known when the remaining coverage will be completed or new sets of maps will be prepared. So far the preparation and updating of maps have resulted from photogrammetric applications and processing of aerial photographs involving time-consuming procedures and costly equipment. Heavy investments in the acquisition of aerial photographs, photogrammetric tools and in personnel training have hampered the production of maps. To overcome these shortcomings and to rapidly produce reliable and geographically referenced topographical and environmental location data for the sugar industry, the Global Positioning System (GPS) technology has been resorted to. The GPS, an advanced information and satellite-based technology tool, provides accurate positions of any object on the surface of the earth in a reference coordinate system. It is used for a wide range of applications from navigational/traffic control, environmental data collection to land surveying. In the sugar industry elsewhere it has been applied to field block mapping and locomotive tracking (Fuelling et al. 1992) and to base mapping for a GIS sugar cane project (Acharya 1995). The experiences gained with GPS applications in the mauritian sugar industry are outlined below.

THE GPS OVERVIEW

The GPS is based on a navigation system called NAVSTAR (NAVigation Satellite Timing And Ranging) developed by the US Department of Defense. The system is comprised of three segments:

the Space segment consisting of a constellation of 24 satellites that orbit the earth at an altitude of about 20 200 kilometres; the Control/Monitor segment involving transmission of data, receiving satellite signals, collecting meteorological data, upload to satellites, commands, etc; and the User segment dealing with various civilian and military applications. Having on board atomic clocks (accurate to within 1sec/300000 yrs) and location information, each satellite continuously sends signals on precise time and position (Beck et al 1987; Hurn 1989; Kruger et al 1994). From a unique coded signal (called Pseudo Random Noise) broadcast by each satellite, the GPS identifies the satellites sending the signals and computes the accurate position of an object (latitude, longitude, altitude) in a coordinate system (World Geodetic System 1984) which is a most precise ellipsoid model description of the earth. Signals from a minimum of three satellites are sufficient for calculation of a relatively good position fix for any point in the X and Y horizontal planes whereas signals from a minimum of four satellites are required for a good position fix for X, Y and Z values.

Position accuracy is achieved to within 30 meters in the coarse acquisition mode (C/A) and from sub-meter to within 10 meters in the P-mode (encrypted code) with code-based single frequency receivers. However Selective Availability, caused by the intentional degradation of signals imposed by the US Department of Defense, limits the position accuracy to within 100 meters (Hurn 1989; Lange 1996). With carrier-phase dual frequency receivers (L1 band =1575.42 MHz and L2 band = 1227.6 MHz) on the other hand position accuracy for geodetic control and precise surveying is achieved to within 1 centimeter. So-called Real-time Kinematic carrier phase GPS receivers coupled with radios/modems are capable of providing precise position fixes to the centimeter level thus allowing errors to be verified on the spot. They also eliminate the need for office post-processing of GPS data, as has been the case with other types of receivers.

The GPS operates worldwide in all weather conditions for 24 hours. For land surveying, the GPS has added advantages over traditional surveying. It does not require the line of sight between objects as it is communicating with satellites in space to calculate the position. It needs only one operator to carry out the survey (3 or more persons with optical instruments). The same GPS user himself may process data with the relevant software for preparing and plotting the required map as digital files or hard copies. The result is that GPS surveys are a lot more productive and less costly than traditional surveys. Various modes of GPS survey techniques have been elaborated (Leick 1990; Trimble Navigation Ltd 1992).

CHARACTERISTICS OF GPS USED, RELATED SOFTWARE / HARDWARE

In 1996, the Mauritius Sugar Industry Research Institute acquired a dual frequency real-time kinematic GPS set known as the Trimble Total Station. The set consists of the following components:

2 receivers of the 4000 SSE series + 2 antennas for satellite reception;

1 handheld Survey Controller-TCD1;

3 radios/modems (TrimTalk) + 3 antennas for radio data communication;

1 tribach, 2 tripods, cables, batteries, poles and other accessories.

The set is a modular hardware package designed to provide the highest data integrity and ease of use. One receiver is configured as a “Master” and kept fixed at a known control point referred to as base station whenever a survey is started. The other receiver is configured as the “Rover” and is a backpack unit for carrying in the field. The GPS set is suitable for short-range control up to 10 km for topographic surveys and stake out operations. As it is of dual frequency and real-time capabilities for kinematic surveying it provides corrected X, Y, Z values (latitude, longitude and altitude) on the spot, thus eliminating the need for post processing of data. It allows 9 channels of L1 P-code and carrier phase and 9 channels of L2 P-code and carrier phase. More than one “Rover” receivers can be used in conjunction with the Master reference unit. Two modes of accuracy are obtained:

i) fine-mode: horizontal = 1 cm + 2ppm x baseline length,
vertical = 2 cm + 2ppm x baseline length,

ii) coarse-mode: ± 1 m.

Up to 3000 survey points can be stored in the system but may be upgraded to store 40 000 points. It supports a wide range of map projections (Plane Local Coordinates, UTM, Lambert Conformal, etc) and is particularly customized to convert WGS-84 coordinates to the Mauritius Coordinate Systems (Lambert Conformal Orthomorphic, Northings & Eastings). The rover receiver can also be mounted on a vehicle to conduct topographic surveys.

Software and hardware

GPSurvey:

This is used to supplement real-time GPS surveying, for example to survey baselines longer than 10 km or for high accuracy control requirements. It further allows mission planning, automatic or manual post processing of baselines, and exporting of coordinates, etc.

TrimMap:

This provides a powerful interface to modern GPS methods and accepts data directly from a wide variety of sources including most handheld data collectors. It calculates projection parameters and allows two-way data transfer between Survey Controller and the computer. It transforms data in WGS-84 ellipsoid coordinates to local coordinate system. Finally, it allows composition of the map for plotting.

TrimContour:

This is the package to generate Triangular Irregular Network (TIN) and contour lines at required intervals.

TrimCalc:

A package that calculates areas and volumes.

Computer hardware and plotters: A pentium Windows-based PC with 64 MB of RAM and 6.4 GB of hard disk. Two plotters, one HP DraftPro pen-plotter of A1 size and the other a HP DesignJet of A4 size.

TOPOGRAPHIC AND CONTOUR MAPPING FOR EX-TEA AREAS

Large scale maps (1:2500) showing appropriate topographic features and primarily 1 or 2m contour lines are essential for the implementation of land planning measures, such as layouts of roads, drains, cane row directions, and erosion control, which can best be planned from the maps prior to their implementation in the field. Proper land planning facilitates mechanized or non-mechanized cultural operations, increases machine efficiency, and enables soil protection measures to be identified. These planning measures have proved essential, when the lands formerly under tea were put under cane, as they are found in a zone receiving high rainfall causing drainage problems and erosion.

As large-scale maps for these areas were not available aerial photographs at scale 1:20 000 were used to produce 1:2500 scale topographic and contour maps of the areas by a foreign contracting service. However the maps showing 2m contour lines as well as other features did not satisfy certain requirements such as references to the national grid coordinates system and certain ground features.

The Trimble GPS Total Station was used to survey the areas so as to rapidly produce 1:2500 scale topographic and 2m contour maps for some 370 ha (example **Figure 1**). These maps were referenced and contained the details required for land planning measures.

Figure 2 illustrates the land-planning map with the new layout of fields, roads and the directions of cane rows. The methodology adopted for the GPS surveys is described in the following.

Figure 1 Topographic and contour map of an area of the ex-tea belt

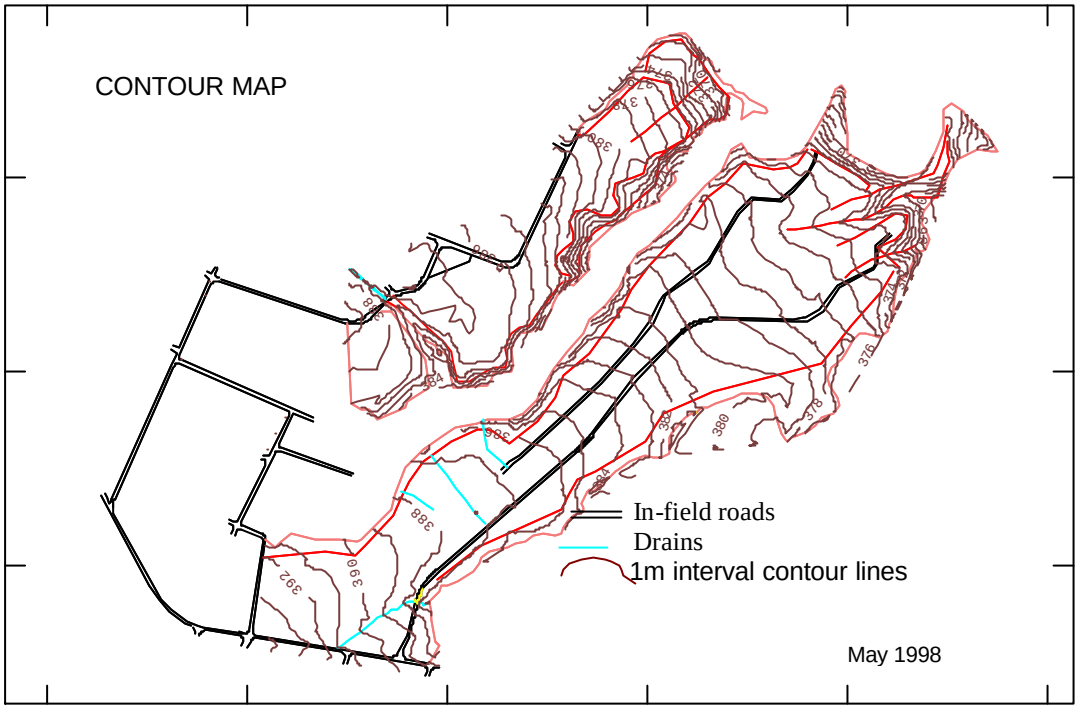
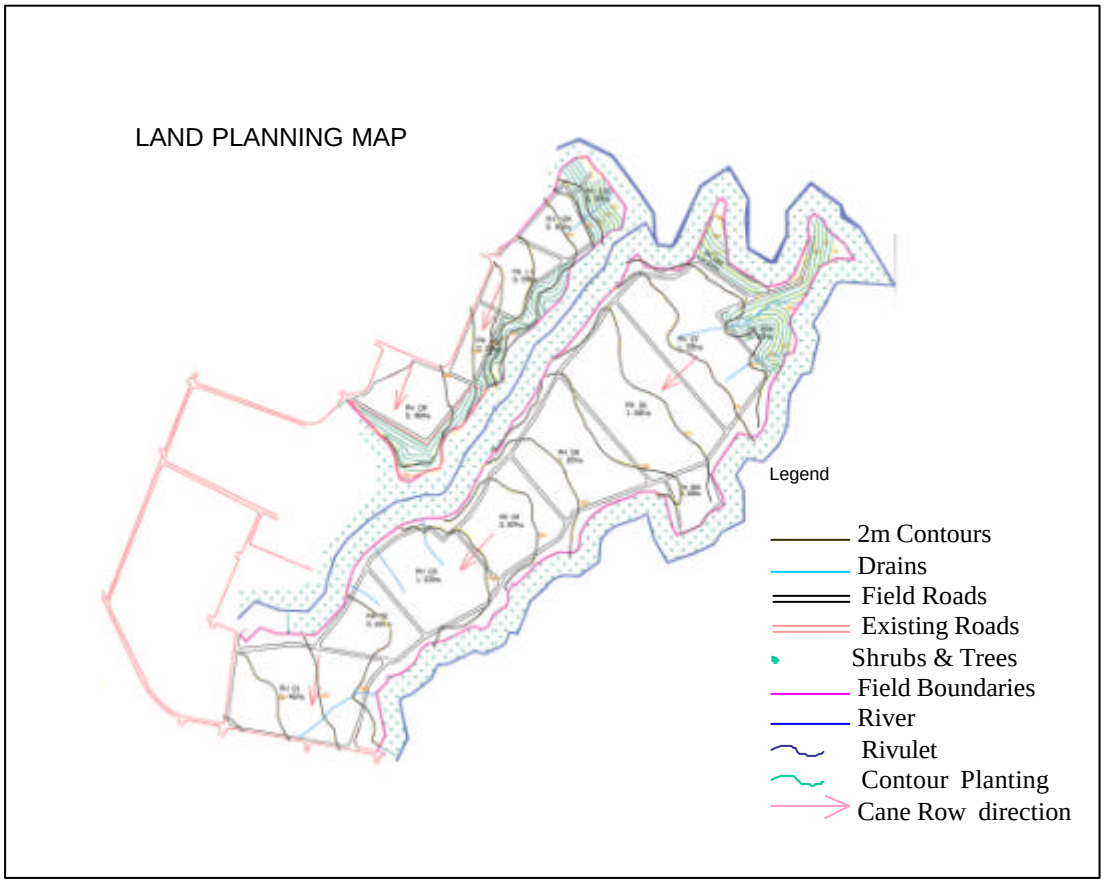


Figure 2 Land planning map of an area of the ex-tea belt Courtesy : S.Seeruttun, Cultural Operations & Weed Agronomy Department, MSIRI



SURVEY METHODOLOGY

As a number of variables (NAVDATA) concerning the satellites and their positions are known in advance, planning of the GPS survey is facilitated. The Trimble GPS Total Station is provided with the QuickPlan software to create an observation schedule by producing satellite visibility plots and reports before proceeding to the field. It enables the best observation periods for a survey session to be determined as well as the number of satellites available and good geometry (various positional angles) of the satellites. Updated information is regularly provided from the satellite "Almanac" and "Ephemeris". On the other hand a field reconnaissance is undertaken to identify physical constraints and evaluate the best approaches to the survey. Other considerations are the identification and collection of established ground control points/benchmarks, so-called trigonometric points, to enable the calibration of the GPS for establishing other reference points. In that way, a planned GPS survey is more productive and time is not wasted during fieldwork when few satellites are available and poor satellite geometry exists.

For surveys of the ex-tea areas (near to the Piton du Milieu Reservoir), the GPS was calibrated from five trigonometric points (situated at Bar Le Duc, Verdun Hill, Réduit roundabout, Candos Hill and Trou aux Cerfs). Two principal reference points were established: one on top of the MSIRI Belle Rive Station and the other on top of the Dubreuil Tea Factory. Depending on the proximity of the area to be surveyed anyone of the reference points was used as a base station. For data link between the two receivers two radios were used, one situated at the site of the Master receiver and the other at the survey site. In certain cases when the topography or trees affected radio communication a third radio was used as a repeater. The fine-mode level of accuracy (horizontal = 1cm; vertical = 2cm) was utilised and point measurements for the topographic survey were recorded by the "stop and go" method. The decision for taking point measurements was based on an evaluation of the varied ground elevation conditions and the occurrence of other features (drains, rock heaps, etc). Point data collection of spot heights for generating 2m-interval contours was based upon recording XYZ values of a measurement at approximately every 15 meters along parallel transects running through the fields. The technique was equivalent to collecting position data on an imaginary grid overlying the field.

The advantage of the grid spacing approach has been discussed (Clark and Lee 1998). The number of spot heights collected per hectare for the area varied according to the grid spacing as shown in **Table 1**. Some personal judgement was also used to create high or low density of points depending upon the sloping nature of the terrain. The efficacy of visual assessment for varying densities of spot height measurements according to important micro-relief differences especially for ditches, depressions, sudden slope breaks, etc has been recognized (Clark pers. comm. 1999).

Table 1 Grid spacing for spot height data collection

Site	Area	Contour lines derived	Spot heights measured		Grid spacing
	ha	*m*	*Total*	*per ha*	*m x m*
1	12.81	2	940	73	12.5 x 12.5
2	70.00	1	2300	33	17.4 x 17.4
3	72.00	1	2400	33	17.4 x 17.4
4	4.82	2	220	46	14.7 x 14.7

GPS DATA PROCESSING

After the GPS survey was completed, the point or position data (X Y Z values) recorded in the handheld system controller were then downloaded to a PC for processing with the TrimMap/TrimContour software. It is best to download recorded data in the computer immediately after the field survey has been completed so that data are not lost if there is a battery failure of the System Controller. As a routine practice the data are controlled for anomalies and redundancy. A conversion of the data referenced in WGS-84 into the required reference datum of Mauritius is carried

out with the TrimMap, after which contour lines are generated and a map composition is undertaken to depict relevant topographic features, contour intervals, scale and legend for final output.

REFERENCE DATUM

For mapping purposes the notion of a reference or map datum is important. The earth is best represented by a mathematical model which is the ellipsoid. However as the shape of the earth is irregular, variations of the ellipsoid are used to fit or reference parts of the earth surface as datums. As a result every datum has a reference ellipsoid and also any point on the earth surface can have different sets of coordinates depending upon the datum used. The GPS datum is the WGS-84 ellipsoid that is applicable to the whole earth. In order to represent the area surveyed by GPS on a map referenced to a local datum, it is necessary that the GPS coordinates of the area should be transformed to the coordinates of the local datum. The transformation is accomplished by inputting a number of ground control points (trigonometric points), which have known values of the local datum. The GPS software performs the necessary computation involving rotation, scale and deflection to transform values for the local datum. Grid coordinates for local datum expressed as Northings and Eastings (including elevations) are often the final coordinates output for most GPS surveys. Comprehensive accounts are given by Brown (1992) on the GPS coordinate system and by Mugnier (1999) on the map datum of Mauritius.

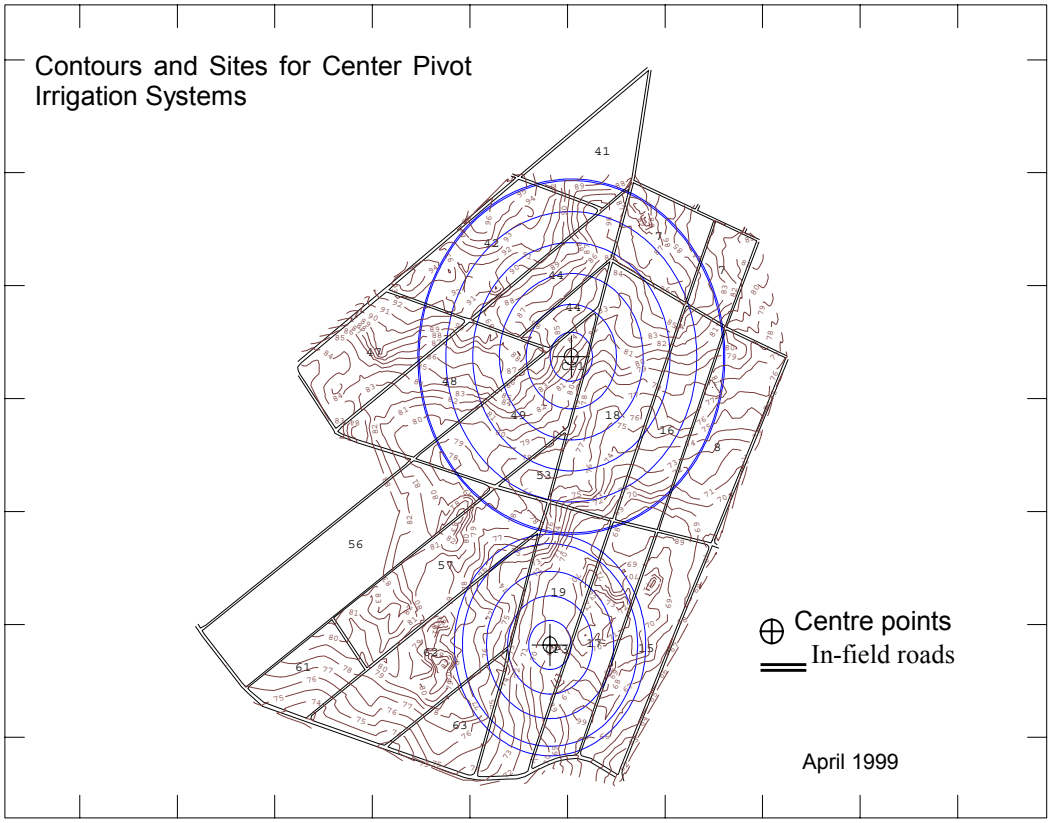
CONTOUR MAPPING FOR IRRIGATION PROJECTS

Contour mapping with the GPS was undertaken for a cane area of 370 ha earmarked for implementing drip irrigation in the north of Mauritius. To satisfy irrigation engineering requirements it was necessary to produce a map showing contour lines at 50-cm intervals to enable the calculation of water pressure at different points, the layout of dripper lines, and slope directions. Emphasis was laid on accurately referencing the contour map to the national grid coordinate system of Northings and Eastings. Owing to the flatness of the terrain visual assessment of ground conditions rather than a grid approach helped to decide on the number of spot heights to be taken. At the end of the survey some 10 to 12 spot heights to the hectare were recorded. The horizontal accuracy was set to ± 10 mm and the vertical accuracy to ± 20 mm. A manual check of the coordinates of the 1:2500 scale contour map produced was conducted by overlaying the map on the existing 1:2500 scale map of the area. This confirmed the output of GPS references to the local grid system.

POSITIONING OF CENTER PIVOT IRRIGATION SYSTEMS

Large scale 1:2500 contour maps are useful for determining the sites of center pivot irrigation systems. In certain cases, however, the pivot sites determined from these maps are not always exact as under- and over-estimation of horizontal/vertical distances of the pivot systems, installed according to indications from studies of these maps, in relation to topographic constraints may result. The published maps are often outdated with regards to certain physical constraints as tall trees, new constructions, electric poles and other forms of development. A 1-2 m error in locating the center points of the pivot systems on the ground may lead to costly operations such as reducing the system arm-lengths, and carrying out additional land cut and fill. The use of the GPS in providing up-to-date realities eliminates difficulties encountered with studies of outdated maps. Using the GPS three center pivot irrigation systems in the north east of Mauritius were laid down in relation to such obstacles like electric poles, trees, marshes and roads. For another area in the south, two center pivot systems were sited as closely as possible with a clearance of just 2m because of critical terrain constrains. The navigation techniques of the GPS revealed to be ideally suited to determine the sites of two close center pivot systems. **Figure 3** shows the example of a 1m contour map produced and the sites of the two close center pivot systems as determined by the GPS.

Figure 3 GPS determined sites for Center Pivot Irrigation Systems



DIGITAL ELEVATION MODEL

Within the scope of a project on the modelling of agro-chemical movements in soil a cane area of about 250 was surveyed with the GPS to provide 2m interval contour lines and sufficient ground elevation data to establish a digital elevation model (DEM) for determining surface flow directions (MSIRI, 1996).

REFERENCE POINTS FOR GIS APPLICATIONS AND OTHER SURVEYS

The application of the geographical information system for the management of sugar cane land has now been well established and adopted. However, certain large scale topographic maps being outdated cannot be used for the digitization of some cartographic features (roads, field boundaries, etc.) for GIS applications. In order to overcome this situation, the digital cartographic documents have been produced from exploitation of aerial photographs. The digital maps however lacked proper geographic coordinate referencing to the local grid system. In this context, it is therefore contemplated to establish permanent networks of ground reference points on the terrain with the GPS.

PROSPECTS

Collection of environmental location data is becoming a necessity as information technology is being increasingly used in mechanized agriculture. Crop and field management is going to be practised at the site-specific levels. There will be requirements for producing spatial variability maps for yield, weeds, diseases/pest and soil characteristics (pH, nitrogen, phosphorus, potassium, organic matter content,

etc). Maps produced will be analyzed and support decisions to enable variable rate applications of fertilizers, herbicides, fungicides, planting material, irrigation water, etc. The objectives will be to optimise yield through variable rate applications of inputs, reduce production costs and provide a base for environmental protection through control of agro-chemical inputs. This evolving form of agriculture is known as Precision Agriculture or Precision Farming (USA National Research Council 1997).

A key tool in enabling precise field variability mapping in Precision Agriculture is the GPS. The GPS unit is mounted on tractors, harvesters and soil sampling vehicles to provide the precise location data for crop and field management. The applications of GPS in Precision Agriculture have been addressed by several researchers (Harrison et al 1992; Auernhammer 1994; Eliason et al. 1994; Lange 1996; Yao and Clark 1999). The prospects of Precision Agriculture, of which the GPS is an important component, have also been investigated for the sugar industry (Bramley et al. 1997; Jhoty and Autrey 1998; Ferreira and Scheepers 1999).

The applications of GPS may be further extended to provide a ground reference system for satellite images and scanned air photos. The latter products are now widely used to produce land use and other themes in agriculture but lack a proper cartographic reference base. With ground control points (GCPs) collected by the GPS it is possible to correct the images/airphotos using the relevant software (e.g OrthoEngine) to provide planimetric corrected images called orthoimages (Cheng and Toutin 1996). Integration of field data/features from these images can then be easily used in a GIS for outputting thematic maps, conducting spatial analyses and building digital elevation models (DEM). It is expected that these techniques will be widely applied in the sugar industry.

As technicians in the sugar industry gradually exploit the full potential of the GIS and develop awareness of the GPS capabilities, they will also find it useful to obtain positional data with GPS for inventorying utilities and other infrastructure, for example water points, surface/sub-surface conduits, pipelines, electric poles, discharge canals, underground cables, etc. Knowledge of the correct mapped positions of these utilities will assist in maintenance operations and in further development.

CONCLUSIONS

The GPS is proving to be a very efficient tool for carrying out detailed surveys in providing precise location data, topographic and contour maps. The present applications of the GPS in the Mauritian sugar industry are at an early stage. As information technology tools and precision farming in the management of agricultural resources are gradually utilised in the industry, the demand for the use of the GPS for various purposes will undoubtedly increase.

ACKNOWLEDGEMENT

I am grateful to the MSIRI Deputy Director (Agronomy) for his comments and to the Director for giving permission to present the paper.

REFERENCES

ACHARYA B. 1995. *Applications of GPS and scanning to Base Mapping: A sugar cane GIS Pilot Project in the Cauca Valley, Colombia*. 1995 ASPRS/ACSM Annual Convention and Exposition Technical Papers. Charlotte, North Carolina, February 27-March 2 1995. Vol. 1, 242-251.

AUERNHAMMER H Ed.. 1994. Global Positioning Systems in Agriculture. Special Issue *Computers and Electronics in Agriculture* 11(1994) 1.

BECK N, DELIKARAOGLOU D, KLEUSBERG A, KRAKIWSKY E J, LACHAPELLE G, LANGLEY R B, NAKIBOGLU M, SCHWARZ K-P, TRANQUILLA J M, VANICEK P and WELLS D. 1987. *Guide to GPS Positioning*. Canadian GPS Associates, New Brunswick, Canada, 1987.

BRAMLEY R G V, COOK S E and MCMAHON G G. eds. 1997. *Precision Agriculture – What can it offer the Australian Sugar Industry?* Proc. of a workshop held at Mercury Inn, Townsville, 10-12 June 1997. CSIRO Land and Water, Townsville.

BROWN A. 1992. The GPS coordinate system explained. *GIS World*, 5(2): 70-71, 1992.

CHENG P and TOUTIN T. 1996. *On-site interactive ground control collection using GPS and geometric modelling*. 1996 ASPRS/ACSM Annual Convention & Exposition Technical Papers. Baltimore, Maryland, April22-25, 1996. Vol. 2 GIS & GPS, pp 8-15.

CLARK RL and LEE R. 1998. Development of Topographic Maps for Precision Farming with Kinematic GPS. *Transactions of the American Society of Agricultural Engineers*, Vol. 41 (4): 909-916, 1998.

ELIASON M, HEANEY D, GODDARD T, GREEN M, MCKENZIE C, PENNEY D, GEHUE H, LACHAPELLE and CANNON ME. 1994. Yield Measurement and Field Mapping with an Integrated GPS system. In: Roberts PC et al. Eds. *Proc. of site-specific management for agricultural systems*, March 27-30, 1994. ASA/CSSA/SSSA, Minneapolis, MN. pp 49-58.

FERREIRA F and SCHEEPERS F. 1999. Applications of satellite technology in the sugar industry. pp 1. In: *Abstracts of the 73rd Annual South African Sugar Technologist's Association*, 2-4 August 1999, Univ. of Natal, Durban.

FUELLING TG, CHAPPEL RJ, MOORE DG and PEASE JC. 1992. GPS for mapping and tracking. Pp 116- 121. In: *Proc. of the 14th Conf. of the Australian Soc. of Sugar Cane Technologists*, 28 April-1May 1992. Mackay, Queensland.

HARRISON JD, BIRRELL SJ, SUDDUTH KA and BORGELT SC. 1992. *Global Positioning System Applications for Site-specific Farming Research*. 1992 International Meeting sponsored by the American Society of Agricultural Engineers, Nashville, Tennessee, December 15-18, 1992. Paper No. 923615.

HURN J. 1989. GPS – *A Guide to the Next Utility*. Trimble Navigation Ltd, Sunnyvale, California, 1989.

JHOTY I and AUTREY JC. 1998. Precision Agriculture – Perspectives for the Mauritian Agriculture. *In* Lalouette JA et al. eds. *Proceedings Annual Meeting of Agricultural Scientists*. Food and Agriculture Research Council, Reduit, Mauritius, 1999.

JHOTY I. 1995. Geographical Information System and related information technology for the management of sugar cane lands. p 33-36. *In*: Antoine R. ed. *Proc. of the first annual meeting of agricultural scientists*, Reduit, Mauritius, 12-13 June 1995. Food and Agricultural Research Council.

KRUGER G, SPRINGER R and LECHNER W. 1994. Global Navigation Satellite Systems (GNSS). *Computers and Electronics in Agriculture* 11(1994) 3-21.

LANGE AF. 1996. Centimeter Accuracy Differential GPS for Precision Agriculture Applications. *In:* Roberts PC et al. Eds. *Proc. of the 3rd International Conference on Precision Agriculture*. June 23-26, 1996. Minneapolis, Minnesota. ASA/CSSA/SSSA. Pp 675-680.

LEICK A. 1990. *GPS satellite sur*veying. John Wiley & Sons, New York. 1990.

MUGNIER CJ. 1999. Grids and Datum – The Republic of Mauritius. *Photogrammetric Engineering and Remote Sensing*, Vol 65 (2), pp 127-128, February 1999.

TRIMBLE NAVIGATION LTD. 1992. *A Field Guidebook for Dynamic Surveying*. Sunnyvale, CA 94088-3642, USA.

USA NATIONAL RESEARCH COUNCIL. 1997. *Precision Agriculture in the 21st Century: Geospatial and Information Technologies in Crop Management*. National Academy Press, Washington, D.C. 149 pp.

YAO H and CLARK RL. 1999. Evaluation of the potential to use sub-meter accuracy GPS receivers to develop topographic maps for precision farming. *In:* Stafford JV. Ed. *Precision Agriculture '99. Papers presented at the 2nd Conference on Precision Agriculture*, Denmark, July 11-15, 1999. pp 847-856.

CROP MODELLING / SIMULATION : AN OVERVIEW

BF Cheeroo-Nayamuth

Mauritius Sugar Industry Research Institute

ABSTRACT

The application of crop modelling in the agricultural field dates back only to the 1970s but models of various types are becoming increasingly accessible to users with different levels of exposure and expertise. Agricultural models are, however, only crude representations of the real systems because of the incomplete knowledge resulting from the inherent complexity of such systems. Judicious use of such models is possible only if the user has a sound understanding of model structure, scope and limitations. Within the local agricultural context, crop modelling is a new discipline and background literature is scarce. This paper provides an overall view of agricultural models, their features, and the implications of model development, testing and application. Potential areas of model application are outlined and the main issues to be considered when using models are listed out.

Keywords : agriculture, models, agricultural systems, empirical models, mechanistic models, static models, dynamic models, deterministic models , stochastic models, simulation and optimising models, model development.

INTRODUCTION

The practice of agriculture is based on knowledge, tradition and conjecture, and agricultural research improves the knowledge that provides the basis for decision-making. Traditional disciplinary research methods have been used to deal with biological and economic problems but have not been entirely successful in handling the inherent complexities of agricultural activities. However, as knowledge is accumulated, results obtained from observation change from being qualitative to being quantitative and mathematics can be adopted as the tool to express biological hypotheses (France and Thornley 1984). Model-building capabilities are developed and it becomes possible to adopt a holistic and quantitative approach to problem solving within the agricultural field.

Owing to the inherent complexity of agriculture, modelling studies started only in the 1970s. Rapid accumulation of knowledge in the agricultural field and the increased accessibility to information technology have contributed to the development of a wide number of agricultural models over the last three decades. A restricted search of the CROP-CD of CAB Abstracts with the keywords 'model' and 'simulation' in the title of journal articles showed that model-related publication rates have evolved from 82 per year in the 1970s to about 270 per year in the 1990s, the main journals being *Transaction of ASAE, Agricultural Systems, Agricultural and Forest Meteorology, Agronomy Journal,* and *Field Crops Research* (**Table 1**). The name of software was mentioned in the title or abstract of only 11 articles between 1973 and 1988 while the corresponding number for the 1989 to 1998 period was 77.

This confirms that crop models are being increasingly developed and investigated, and their applications reported. In the Mauritian agricultural sector, modelling is a new discipline and basic background information is not easily available. Hence, modelling could be perceived with some bias. Lack of awareness about model structure, possibilities and limitations, may result in too high expectations turning into dis proportionate disregard upon the least case of failure.

The objective of this paper is to provide the basic information on crop modelling and its adoption. A broad overview of a model, with emphasis on the simulation approach as well as highlights of model development and verification procedures, will be provided. Applicability and limitations of the modelling approach will be summarised.

Table 1 Publication rate of articles with modeling / simulation in title

Period →	1973-80	1981-88	1989-92	1993-95	1996-98	Total
Interval *yrs* →	8	8	4	3	2.33	26.33
Total number of articles over period	660	879	877	817	622	3855
Total number of articles per year	82	110	219	272	267	950
Transaction of ASAE	50	62	32	23	10	177
Agricultural Systems	15	31	47	34	29	156
Agronomy Journal	28	23	23	34	27	135
Dissertation Abstract International	61	63				124
Agricultural and Forest Meteorology		16	36	15	26	93
Agricultural Meteorology	23	6				29
Field Crops Research	5	9	15	21	11	61
Annals of Botany	10	20	6	7	12	55
Remote Sensing of environment		13	6	18	13	50
Environmental Entomology	11	18	13		6	48
Plant and Soil	9	11		7	20	47
Phytopathology	8	16	11	8		43
Plant Physiology	8	12	14	8		42
Ecological Modeling			15	16	8	39
Agricultural Water Management	3	6	4	13	10	36
Soil Science Society of America Journal	7	6	16	7		36
Journal of Agricultural Engineering Research		8	6	9	12	35
Journal of Applied Ecology	12	8	6		6	32
Journal of Experimental Botany	9	7	8	8		32
Crop Science	12		13		6	31
Journal of Agricultural Science	12	7		7	5	31
Agronomie		17	10			27
Journal of Theoretical Biology	18	7				25
European Journal of Agronomy				17	7	24
Fertilizer Research		5	17			22
Canadian Journal of Soil Science	7			9	5	21
Journal of Economic Entomology		7	6		5	18
Weed Science			8		9	17
International Rice Research Notes			8		6	14
Plant, Cell and Environment		9	5			14
Theoretical an Applied Genetics	5			8		13
Australian Journal of Soil Research	12					12
Weed Research				12		12
Australian Journal of Agricultural Research			6		5	11
Computers and Electronics in Agriculture					11	11
Southern journal of agricultural economics	5	5				10
Aspects of Applied Biology			9			9
Soil Science	9					9
Acta-Oecologica		8				8
ASAE - Annual International Meeting					8	8
Modelling in applied Biology					8	8
American Journal of Agricultural Economics		7				7
International AgroPhysics					7	7
Journal of Agronomy and Crop Science				7		7
South African Journal of Plant and Soil			7			7

Source: CROP-CD, CAB Abstracts

MODELLING AGRICULTURAL SYSTEMS

Complexity of agricultural systems

Agricultural systems are characterised by having many organisational levels. From the individual components within a single plant or animal cell, through constituent plants or animals to farms or a whole agricultural region or nation, to the world agricultural economy, lies a whole range of agricultural systems. Since the core of agriculture is concerned with plants (crops and pasture), the level that is of main interest to the agricultural modeller is the plant. Reactions and interactions at the level of tissues and organs are combined to form a picture of the plant that is then extrapolated to the crop and farm output.

Even after setting the boundary of the system to focus on the plant, the modeller still has to integrate knowledge from a spectrum of disciplines (biology, physics, chemistry, economics and mathematics) and to specify interactions of different nature, namely, physical (e.g., weather, light and soil moisture), chemical (e.g., CO_2 concentration and nutrients), biological (e.g., pests, diseases, weeds and other plants in the community) (Stockle 1989). The complexity of the system is further increased by spatial and temporal variability in terms of climate and soil characteristics, genetic diversity and the wide range of management options adopted by farmers.

MODELS IN AGRICULTURE

Agricultural models are mathematical equations that represent the reactions that occur within the plant and the interactions between the plant and its environment. Owing to the complexity of the system and the incomplete status of present knowledge, it becomes impossible to completely represent the system in mathematical terms and hence, agricultural models are but crude images of the reality (Passioura 1973, 1996). Unlike in the fields of physics and engineering, universal models do not exist within the agricultural sector. Models are built for specific purposes and the level of complexity is accordingly adopted. Inevitably, different models are built for different subsystems and several models may be built to simulate a particular crop or a particular aspect of the production system (**Table 2**).

Features of crop models

The main aim of constructing crop models is to obtain an estimate of the harvestable (economic) yield. According to the amount of data and knowledge that is available within a particular field, models with different levels of complexity are developed. Grouping of models has been attempted by various authors (Brockington, 1979; France and Thornley 1984; Brown and Rothery 1994) but strong demarcations cannot be made since a model generally possesses the characteristics of more than one group. The most pertinent aspects of crop models are described below.

Empirical model

Empirical models are direct descriptions of observed data and are generally expressed as regression equations (with one or a few factors) and are used to estimate the final yield. Examples of such models include the response of crop yield to fertiliser application, the relationship between leaf area and leaf size in a given plant species and the relationship between stalk height alone or coupled with stalk number and / or diameter and final yield in the sugarcane. In the sugarcane industry, the relationship between water use efficiency and final cane yield (8-10t of cane ha^{-1} for every 100 mm of water) is widely used for irrigation planning (Thompson 1976; Kingston 1994).

These models are crude and are good means for interpolation at the location and the range over which they have been derived (Sinclair and Seligman 1996) but it is advisable to avoid extrapolation. For example, under contrasting conditions, the above water use efficiency-cane yield relationship may not hold (Data cited by Robertson and Muchow 1994).

Mechanistic model

A mechanistic model is one that describes the behaviour of the system in terms of lower-level attributes. Hence, there is some mechanism, understanding or explanation at the lower levels. These models have the ability to mimic relevant physical, chemical or biological processes and to describe how and why a particular response results. The modeller usually starts with some empirism and as knowledge is gained additional parameters and variables are introduced to explain crop yield. Thus, the modeller adopts a reductionist approach. Most crop growth models, namely those mentioned in Sections 3 and 4, fall within this category.

Static and dynamic models

A static model is one that does not contain time as a variable even if the end-products of cropping systems are accumulated over time, e.g., the empirical models. In contrast dynamic models explicitly incorporate time as a variable and most dynamic models are first expressed as differential equations:

$dy/dt = f(X)$ Where y = an attribute of the system (animal liveweight)
t = time variable
f = some function, possibly of y, t and other parameters.

The integration of the above equation will give the actual behaviour of the system over time. It may be possible that at some stage, the rate of change of the system becomes zero such that $dy/dt = 0$ and therefore $f(X) = 0$, and the model is then static (France and Thornley, 1984). This continuum from dynamic to static state of dynamic models was also reported by Brown and Rothery (1994).

Deterministic and stochastic models

A deterministic model is one that makes definite predictions for quantities (e.g., animal liveweight, crop yield or rainfall) without any associated probability distribution, variance, or random element. However, variations due to inaccuracies in recorded data and to heterogeneity in the material being dealt with, are inherent to biological and agricultural systems (Brockington, 1979). In certain cases, deterministic models may be adequate despite these inherent variations but in others they might prove to be unsatisfactory e.g. in rainfall prediction. The greater the uncertainty in the system, the more inadequate deterministic models become.

When variation and uncertainty reaches a high level, it becomes advisable to develop a stochastic model that gives an expected mean value as well as the associated variance. However, stochastic models tend to be technically difficult to handle and can quickly become complex. Hence, it is advisable to attempt to solve the problem with a deterministic approach initially and to attempt the stochastic approach only if the results are not adequate and satisfactory (Thornley and Johnson 1990).

Simulation and optimising models

Simulation models form a group of models that is designed for the purpose of imitating the behaviour of a system. They are mechanistic and in the majority of cases they are deterministic. Since they are designed to mimic the system at short time intervals (daily time-step), the aspect of variability related to daily change in weather and soil conditions is integrated. The short simulation time-step demands that a large amount of input data (climate parameters, soil characteristics and crop parameters) be available for the model to run. These models usually offer the possibility of specifying management options and they can be used to investigate a wide range of management strategies at low costs. Most crop models that are used to estimate crop yield fall within this category.

Optimising models have the specific objective of devising the best option in terms of management inputs for practical operation of the system. For deriving solutions, they use decision rules that are consistent with some optimising algorithm. This forces some rigidity into their structure resulting in restrictions in representing stochastic and dynamic aspects of agricultural systems. Linear and non-linear programming were used initially at farm level for enterprise selection and resource allocation. Later, applications to assess long-term adjustments in agriculture, regional competition, transportation studies, integrated production and distribution systems as well as policy issues in the adoption of technology, industry re-structuring and natural resources have been developed (Wegener 1994).

Optimising models do not allow the incorporation of much biological details and may be poor representations of reality. Using the simulation approach to identify a restricted set of management options that are then evaluated with the optimising models has been reported as a useful option (Swartzman and Van Dyne 1972; Crabtree 1972; Trebeck and Hardaker 1972).

Table 2 Some crop models reported in recent literature

Software	Details	References
SLAM II	Forage harvesting operation	Buck et al., 1988
SPICE	Whole plant water flow	Cruiziat and Thomas, 1988
REALSOY	Soyabean	Meyer and Curry, 1986
MODVEX	Model development and validation system	McKinion, 1986
IRRIGATE	Irrigation scheduling model	Tscheschke et al., 1978
COTTAM	Cotton	Jackson et al. 1990
APSIM	Modelling framework for a range of crops	McCown et al., 1996
GWM	General weed model in row crops	Wiles et al., 1996
MPTGro	Acacia spp.and Leucaena Spp.	Harrington and Fownes, 1996
GOSSYM-COMAX	Cotton	McKinion et al., 1996
CropSyst	Wheat & other crops	Stockle et al., 1994
SIMCOM	Crop (CERES crop modules) & economics	Bootes et al., 1996
Unnamed	Wheat	O'Leary and Connor, 1996
LUPINMOD	Lupin	Fernandez et al., 1996
TUBERPRO	Potato & disease	Nemecek et al., 1996
SIMPOTATO	Potato	Rosenzweig et al., 1996
Unnamed	Citrus	Rosenzweig et al., 1996
WOFOST	Wheat & maize, Water and nutrient	Supit et al., 1997
WAVE	Water and agrochemicals	Vanclooster et al., 1994
SUCROS	Crop models	Spitters et al., 1988
ORYZA1	Rice, water	Kropff et al. 1994
SIMRIW	Rice, water	Horie, 1987
SIMCOY	Corn	Place and Brown, 1987
Unnamed	Alfalfa nematode, water	Sperow and Lybecker, 1998
Unnamed	Kiwifruit	Lescourret et al., 1998
CERES-Rice	Rice, water	Alocilja and Richie, 1998
GRAZPLAN	Pasture, water, lamb	Moore et al., 1997
EPIC	Erosion Productivity Impact Calculator	Williams et al., 1984
CERES	Series of crop simulation models	Jones et al., 1984
DSSAT	Framework of crop simulation models including modules of CERES, CROPGRO and CROPSIM	Tsuji et al., 1994
PERFECT		Littleboy et al. (1989)
QCANE	Sugarcane, potential conditions	Liu and Kingston, 1995
AUSCANE	Sugarcane, potential & water stress conds., erosion	Jones et al., 1989
CANEGRO	Sugarcane, potential & water stress conds	Inman-Bamber, 1995
APSIM-Sugarcane	Sugarcane, potential growth, water and nitrogen stress	Keating et al., 1999
NTKenaf	Kenaf, potential growth, water stress	Carberry and Muchow, 1992.

MODEL DEVELOPMENT

Model structure

As soon as enough scientific knowledge about the growth pattern, the growth-controlling factors and the interactions that are dominant within a particular cropping system becomes available, model building can be initiated.Knowing the desired output (crop yield), one major equation would be identified. In the next step, the factors that control daily growth would be identified. Then, the biomass would be partitioned to the economic portion and the stay-over.

These would be specified as mathematical functions with conditional rules and would be looped over the selected timestep. Thus,

Yield $_{yesterday}$ = seed planted
START
Read today's solar radiation
Proportion of radiation intercepted = Function of canopy status
Plant growth = Solar radiation X % radiation intercepted X Radiation use efficiency
Yield $_{today}$ = yield $_{yesterday}$ + growth $_{today}$.
Go back to START Until an END is put to the system.

In the next step, a detailed flow chart, e.g., a maize simulation model (Muchow et al. 1990), is constructed such that the major crop reactions and interactions are specified:

Phenological development (vegetative development, canopy expansion, silking, crop-end is controlled by thermal time;

Photosynthesis is then derived as a function of canopy light interception and a radiation use efficiency factor; and as soon as silking occurs, daily biomass is allocated to maintenance and grain filling until crop end is encountered.

Finally, the software is written in a computer language, usually FORTRAN. Complex equations coupled with extensive looping demand that models be run on computers to ensure error-free manipulation.

The first step of model construction is completed when all programming, mathematical, computational and numerical errors are eliminated.

The above-named example of a simulation model gives crop growth under non-limiting conditions, and the main use of such models is to determine potential yields. Since potential growth condition is not a common feature in cropping systems, additional relationships would be specified in order for the model to have an application value. The major limiting factor (e.g., water stress, nitrogen stress, competition from weeds or disease outburst) is then identified and its effects on leaf area development, radiation use efficiency and partitioning factors are then derived and expressed mathematically.

Modelling crops like the sugarcane demands more elaborate equations that require substantial human and financial inputs. Firstly, basic research on crop physiology and growth demands that a larger number of samples be treated over a single cycle. Secondly, there are the carry-over effects (e.g., soil moisture, status of crop stand) from one ratoon to the next to be considered. Thirdly, it is the vegetative rather than the reproductive parts of the plant that are of economic value. Fourthly, 'vegetative growth' and 'ripening' occur simultaneously as soon as the first few internodes are formed, and partitioning of biomass can switch more than once over a crop cycle in response to varying climatic conditions.

Crop model development is a collaborative endeavour that necessitates the expertise of crop specialists with good insights of related disciplines as well as the support of researchers from other scientific areas, mathematicians and programmers. Model building is an expensive enterprise and most researchers would be involved in the application of an existing model to a new situation rather than in model development.

Model calibration

Model calibration involves the modification of some model parameters such that data simulated by the error-free model fit the observed data. In many instances, even if a model is based on observed data, simulated values do not exactly comply with the observed data and minor adjustments have to be made for some parameters (Wegener 1994). Non-compliance may arise from sampling errors as well as from incomplete knowledge of the system. Alternatively, it may arise when the model is used in a situation that is markedly different from the one under which it was developed. The calibration procedure will be illustrated with a few parameters used in APSIM-Sugarcane of the Agricultural Production Systems SIMulator (Mc Cown et al. 1996) in the context of the mauritian sugar industry.

The APSIM-Sugarcane model is a physiologically-based description of sugarcane growth in relation to climate, water and nitrogen, using a daily time-step, and developed under Australian conditions for varieties Q96 and Q117. It is designed to simulate a uniform field of cane and predict on an area basis cane and sucrose yields, biomass, nitrogen uptake and partitioning to leaf and stem (Keating et al. 1999). The soil water and nitrogen flow, and the residue decomposition modules have been described by Probert et al. (1998). The major implication of using the model in Mauritius was the switch in variety and varietal difference was accountable to canopy development, biomass partitioning patterns, and onset of stalk development and sucrose accumulation.

From growth analysis data collected in Mauritius (Cheeroo-Nayamuth et al. 1993), the leaf size along the stalk (to specify leaf area index (LAI) development) and biomass partitioning ratios were computed for three contrasting varieties (R 570, M 13/56 and M 555/60) (Cheeroo-Nayamuth 1998; Cheeroo-Nayamuth et al. 1999). Running the model with the derived coefficients underestimated LAI development and subsequently cane and sucrose productions in the ratoon crops. Model simulations were improved when the partitioning ratio of biomass into cane was arbitrarily decreased to account for the possibility that part of the dead leaf component was not recovered at sampling (Cheeroo-Nayamuth 1998; Cheeroo-Nayamuth et al. 1999). Variations in observed (Ratoon 1) and incomplete (Ratoon 2) data implied that fit of observed and simulated data could not be totally achieved.

Model validation

The model validation stage involves the confirmation that the calibrated model closely represents the real situation. The procedure consists of a comparison of simulated output and observed data that have not been previously used in the calibration stage. Ideally, all mechanistic models should be validated both at the level of overall system output and at the level of internal components and processes. The latter is an important aspect because due to the occurrence of feedback loops in biological systems, good prediction of system's overall output could be attributed to compensating internal errors (Van Keulen, 1976). However, validation of all the components is not possible due to lack of detailed datasets and the option of validating only the determinant ones is adopted. For example, in a soil-water-crop model, it is important to validate the extractable water and leaf area components since biomass accumulated is heavily dependent on these.

The methodology of model validation is still rudimentary. The main reason is that, unlike the case of disciplinary experiments, a large set of hypotheses is being tested simultaneously in a model. Furthermore, biological and agricultural models are reflections of systems for which the behaviour of some components is not fully understood and differences between model output and real systems cannot be fully accounted for.

The validation of system simulation models at present is further complicated by the fact that field data are rarely so definite that validation can be conclusive. This results from the fact that model parameters and driving variables are derived from site-specific situations that ideally should be measurable and available. However, in practice, plant, soil and meteorological data are rarely precise and may come from nearby sites. At times, parameters that were not routinely measured may turn out to be important and they are then arbitrarily estimated. Measured parameters also vary due to inherent soil heterogeneity over relatively small distances and to variations arising from the effects of husbandry practices on soil properties. Crop data reflect soil heterogeneity as well as variation in environmental factors over the growing period. Finally, sampling errors also contribute to inaccuracies in the observed data.

Validation procedures involve both qualitative and quantitative comparisons. Before starting the quantitative tests, it is advisable to qualitatively assess time-trends of simulated and observed data for both internal variables and systems outputs. Major discrepancies can be detected visually and these can be corrected before any quantitative tests are attempted. Quantitative comparison is generally restricted to a linear regression of the observed on simulated data (or vice versa), the expectation being a regression line with slope = 1 and intercept = 0 in the ideal case (Jones and Kiniry 1986; Jones et al. 1989; Hammer and Muchow 1994; Carberry and Muchow 1992; Keating et al. 1999; Cheeroo-Nayamuth et al. 1999). Adjusted R^2 and root mean square deviation are usually adopted to assess the goodness-of-fit despite objections raised by Thornton and Hansen (1996), Mitchell (1997) and Analla (1998).

Inadequate predictions of model outputs may require "re-fitting" of the regression curves or fine-tuning of one or more internal variables. This exercise should be undertaken with care because arbitrary changes may lead to changes in model structure that may limit the use of the model as a predictive tool. In some cases, it is best to seek more reliable data through further experimentation than embarking on extensive modification of model parameters to achieve an acceptable fit to doubtful data. This decision relies on the modeller's expertise and rigour as well as on human resources and time available to invest in fine-tuning model predictions.

MODEL USES AND LIMITATIONS

Models are developed by agricultural scientists but the user-group includes the latter as well as breeders, agronomists, extension workers, policy-makers and farmers. As different users possess varying degrees of expertise in the modelling field, misuse of models may occur. Since crop models are not universal, the user has to choose the most appropriate model according to his objectives. Even when a judicious choice is made, it is important that aspects of model limitations be borne in mind such that modelling studies are put in the proper perspective and successful applications are achieved.

Misperceptions and limitations of models

Agricultural systems are characterised by high levels of interaction between the components that are not completely understood. Models are, therefore, crude representations of reality. Wherever knowledge is lacking, the modeller usually adopts a simplified equation to describe an extensive subsystem. Simplifications are adopted according to the model purpose and / or the developer's views, and therefore constitute some degree of subjectivity.

Models that do not result from strong interdisciplinary collaboration are often good in the area of the developer's expertise but are weak in other areas. Model quality is related to the quality of scientific data used in model development, calibration and validation (Section 3).

When a model is applied in a new situation (e.g., switching sugarcane variety discussed above), the calibration and validation steps are crucial for correct simulations. The need for model verification arises because all processes are not fully understood and even the best mechanistic model still contains some empirism making parameter adjustments vital in a new situation.

Model performance is limited to the quality of input data. It is common in cropping systems to have large volumes of data relating to the above-ground crop growth and development, but data relating to root growth and soil characteristics are generally not as extensive. Using approximations may lead to erroneous results. Large variations in wheat yields (4.5 to 8.0 t ha^{-1}) attributable to within-field soil heterogeneity were reported by Russell and Van Gardingen (1996). Hence, the use of average values of soil characteristics as model inputs could lead to some errors in simulated output.

Most simulation models require that meteorological data be reliable and complete. Meteorological sites may not fully represent the weather at a chosen location. In some cases, data may be available for only one (usually rainfall) or a few (rainfall and temperature) parameters but data for solar radiation, which is important in the estimation of photosynthesis and biomass accumulation, may not be available. In such cases, the user would rely on generated data. At times, records may be incomplete and gaps have to be filled. Using approximations would have an impact on model performance. Nonhebel (1994) has

reported that simulated wheat yield was overestimated under potential conditions and underestimated under water-limiting conditions when generated meteorological data were used with SUCROS87 (Spitters et al. 1989).

Model users need to understand the structure of the chosen model, its assumptions, its limitations and its requirements before any application is initiated, e.g, using a model like QCANE, developed for cane growth under non-limiting conditions, would lead to erroneous output and analysis if it is used to simulate under water or nitrogen stress conditions.

At times, model developers may raise the expectations of model users beyond model capabilities. Users, therefore, need to judiciously assess model capabilities and limitations before it is adopted for application and decision-making purposes.

Generally, crop models are developed by crop scientists and if interdisciplinary collaboration is not strong, the coding may not be well-structured and model documentation may be poor. This makes alteration and adaptation to simulate new situations difficult, specially for users with limited expertise. Finally, using a model for an objective for which it had not been designed or using a model in a situation that is drastically different from that for which it had been developed would lead to model failure.

Model uses

The above points may give the impression that crop modelling has a bleak future but recent literature confirms the contrary. Simulation modelling is increasingly being applied in research, teaching, farm and resource management, policy analysis and production forecasts. A summary of the potential benefits that can be derived from using the modelling approach was described by Boote et al. (1996). These authors grouped model applications into three categories, namely, research tools, crop system management tools, and policy analysis tools. A summary of some specific applications within the different groups follows:

As research tools

Research understanding: Model development ensures the integration of research understanding acquired through discreet disciplinary research and allows the identification of the major factors that drive the system and can highlight areas where knowledge is insufficient. Thus, adopting a modelling approach could contribute towards more targeted and efficient research planning. For example, changing the plant density in a sugar beet model resulted in model failure (Loomis et al. 1976). This failure stimulated studies that gave additional information concerning biomass partitioning in the sugar beet (Ropoport and Loomis 1986).

Integration of knowledge across disciplines: Adoption of a modular approach in model coding allows the scientist to pursue his discipline-oriented research in an independent manner and at a later stage to integrate the acquired knowledge into a model. For example, the modular aspect of the APSIM software (Mc Cown et al. 1996), allows the integration of knowledge across crops as well as across disciplines for a particular crop. Adoption of a modular framework also allows for the integration of basic research that is carried out in different regions, countries and continents. This ensures a reduction of research costs (e.g., through a reduction in duplication of research) as well as the collaboration between researchers at an international level.

Improvement in experiment documentation and data organisation: Simulation model development, testing and application demand the use of a large amount of technical and observational data supplied in given units and in a particular order. Data handling forces the modeller to resort to formal data organisation and database systems (Prestwidge et al. 1994; IBSNAT 1988, 1990). The systematic organisation of data enhances the efficiency of data manipulation in other research areas (e.g., productivity analysis, change in soil fertility status over time)

Genetic improvement: As simulation models become more detailed and mechanistic, they can mimic the system more closely. More precise information can be obtained regarding the impact of different genetic traits on economic yields and these can be integrated in genetic improvement programs, e.g.,

the NTKenaf model (Muchow and Carberry 1993a). Other workers have used the modelling approach to design crop ideotypes for specific environments (Muchow and Carberry 1993b).

Yield analysis: When a model with a sound physiological background is adopted, it is possible to extrapolate to other environments. The use of several simulation models to assess climatically-determined yield in various crops has been mentioned by Boote et al. (1996). The CANEGRO model (Inman-Bamber et al. 1993) has been used along the same lines in the South African sugar industry. Through the modelling approach, quantification of yield reductions caused by non-climatic causes (e.g., delayed sowing, soil fertility, pests and diseases) becomes possible. Almost all simulation models have been used for such purposes. Simulation models have also been reported as useful in separating yield gain into components due to changing weather trends, genetic improvements and improved technology (Bell and Fischer 1994).

As crop system management tools

Cultural and input management: Management decisions regarding cultural practices and inputs have a major impact on yield. Simulation models, that allow the specification of management options, offer a relatively inexpensive means of evaluating a large number of strategies that would rapidly become too expensive if the traditional experimentation approach were to be adopted. Many publications are available describing the use of simulation models with respect to cultural management (planting and harvest date, irrigation, spacing, selection of variety type) and input application (water and fertiliser). In the Mauritian sugar industry, the evaluation of the impact of alternative harvest dates and irrigation strategies on cane and sucrose yields was achieved using the APSIM-Sugarcane model (Cheeroo-Nayamuth 1998).

Risks assessment and investment support: Using a combination of simulated yields and gross margins, economic risks and weather-related variability can be assessed. These data can then be used as an investment decision support tool. The APSIM-Sugarcane model successfully demonstrated the variation in economic risk of sugarcane production at Medine, Reduit and Pamplemousses in Mauritius, and provided good indications of potential irrigation and investment strategy to be adopted at these locations (Cheeroo-Nayamuth 1998).

Site-specific farming: Profit maximisation may be achieved by managing farms as sets of sub-units and providing the required inputs at the optimum level to match variation in soil properties across the farm. Such an endeavour is attainable by coupling simulation models with geographic information systems (GIS) to produce maps of predicted yield over the farm. But, one of the prerequisites is a systematic characterisation of units that may prove costly. Such applications of simulation models have been reported by Wegener (1994) and Jones (1993).

As policy analysis tools

Best management practices (BMP): Models having chemical leaching or erosion components can be used to determine the best practices over the long-term. The EPIC model has been used to evaluate erosion risks due to cropping practices and tillage (Williams et al. 1984, 1989).

Yield forecasting: Yield forecasting for industries over large areas is important to the producer (harvesting and transport), the processing agent (milling period) as well as the marketing agency. The technique uses weather records together with forecast data to estimate yield across the industry. This technique was illustrated using CERES-Maize over the corn belt of the USA (Hodges et al. 1987).

Introduction of a new crop: Agricultural research is linked to the prevailing cropping system in a particular region. Hence, data concerning the growth and development of a new crop in that region would be lacking. Developing a simulation model based on scientific data collected elsewhere and a few datasets collected in the new environment helps in the assessment of temporal variability in yield using long-term climatic data. Running the simulations with meteorological data in a balanced network of locations also helps in locating the industry. Such a study was undertaken relative to the proposed introduction of a fibre industry in Northern Australia (Carberry et al. 1992).

Global climate change and crop production: Increased levels of CO_2 and other greenhouse gases are contributing to global warming with associated changes in rainfall pattern. Assessing the effects of these changes on crop yield is important at the producer as well as at the government level for planning purposes. Despite objections raised by Passioura (1996), the simulation approach remains the best tool for quantifying these effects. The CROPGRO, CERES and EPIC models, AUSCANE as well as many others have been used to quantify yield change resulting from global climate change. In Mauritius, the APSIM-Sugarcane model was used to assess the vulnerability of the sugar industry to climate change and to quantify the impact of a limited range of mitigation possibilities (e.g., irrigation adoption, variety type and harvest date) on cane and sucrose yields (Cheeroo-Nayamuth and Nayamuth 1999).

CONCLUDING REMARKS

Agricultural systems are complex entities involving a large amount of technical data from various disciplines for adequate elaboration of crop growth models. As investments in model development are high, most researchers are involved in model application rather than in model development. With decreasing costs of computing facilities, models are becoming accessible to a wide range of users with differing degrees of expertise in the modelling field. Knowledge of crop growth and development being incomplete, even the most rigorous model includes some approximations and, therefore, possesses some limitations. Proper understanding of these limitations is important when models are used.

Nevertheless, crop models can be used for a wide range of applications. As research tools, model development and application can contribute to identify gaps in our knowledge, thus enabling more efficient and targeted research planning. Models that are based on sound physiological data are capable of supporting extrapolation to alternative cropping cycles and locations, thus permitting the quantification of temporal and spatial variability. Over a relatively short time span and at comparatively low costs, the modeller can investigate a large number of management strategies that would not be possible using traditional methodologies. Despite some limitations, the modelling approach remains the best means of assessing the effects of future global climate change, thus helping in the formulation of national policies for mitigation purposes. Other policy issues, like yield forecasting, industry planning, operations management, consequences of management decisions on environmental issues, are also well supported by modelling.

As knowledge is accumulated through further research, models are improved and new models are developed. Also, as more performing models become available and users' experience grows, confidence in the modelling approach will be reinforced and models will be put to more intensive use.

REFERENCES

ALOCILJA EC and RICHIE JT. 1988. *Upland rice simulation and its use in multicriteria optimization*. University of Hawaii and Michigan State University, IBSNAT. 95pp.

ANALLA M. 1998. Model validation through the linear regression fit to actual versus predicted values. *Agricultural Systems*, 57 : 115-119.

BELL MA and FISCHER RA. 1994. Using yield prediction models to assess yield gains: A case study for wheat. *Field Crops Research*, 36 : 161-166.

BOOTE KJ, JONES JW and PICKERING, NG. 1996. Potential uses and limitations of crop models. *Agronomy Journal*, 88 : 704-716.

BOTES JHF, BOSCH DJ and OOSTHUIZEN LK. 1996. A simulation optimization approach for evaluating irrigation information. *Agricultural Systems*, 51 : 165-184.

BROCKINGTON NR. 1979. *Computer Modelling in Agriculture*. Oxford University press, UK.

BROWN and ROTHERY. 1994. *Models in Biology: Mathematics, Statistics and Computing*. John Wiley & Sons Ltd. England. 688pp.

BUCK-NL; VAUGHAN-DH; HUGHES-HA. 1988. A general-purpose simulation program for agricultural operations. *Computers and Electronics in Agriculture*, 3 : 29-44.

CARBERRY PS, MUCHOW RC and MCCOWN RL. 1992. A simulation model of kenaf for assisting fibre industry planning in Northern Australia. IV. Analysis of climatic risks. *Australian Journal of Agricultural Research*, 44 : 713-730.

CARBERRY PS, MUCHOW RC and MCCOWN RL. 1992. A simulation model of kenaf for assisting fibre industry planning in Northern Australia. III. Model description and validation. *Australian Journal of Agricultural Research*, 43 : 1527-45.

CHEEROO- NAYAMUTH BF, ROBERTSON MJ, WEGENER MK and NAYAMUTH ARH. 1999. Using a model to assess potential and attainable sugarcane yield in Mauritius. *Field Crops Research* (Submitted).

CHEEROO-NAYAMUTH BF. 1998. *Evaluation of the APSIM-Sugar model in the Mauritian sugar industry: validation and economic analysis of sugarcane*. MAgrEcon Thesis, Department of Agricultural Economics, University of Queensland, St Lucia, Australia. 228pp.

CHEEROO-NAYAMUTH FC, NAYAMUTH ARH and SOOPRAMANIEN GC.. Early Ripening Trial - MSIRI Progress Report 1993. [Unpublished]

CHEEROO-NAYAMUTH FC, NAYAMUTH ARH. 1999. *Vulnerability and adaptation assessment of the sugarcane to climate change*. National Climate Committee, Mauritius Meteorological Services and Mauritius Sugar Industry Research Institute, MSIRI, Reduit, Mauritius. 40pp.

CRABTREE JR. 1972. The development of a milk production model. *Oxford Agrarian Studies*, **1**. 779-786.

CRUIZIAT P and THOMAS R. 1988. SPICE – a circuit simulation program for physiologists. Agronomie, 8 : 613-623

DENT JB and ANDERSON JR. 1971. Systems, management and agriculture. *In* Dent J.B. and Anderson J.R. eds. *Systems Analysis in Agricultural Management*. John Wiley and Sons, Australasia, PTY Ltd., Sydney-New York-London-Toronto.

FERNANDEZ EJ, LOPEZ-BELLIDO L, FUENTES M and FERNANADEZ J. 1996. LUPINMOD: a simulation model for white lupin crop. *Agricultural Systems*, 52 : 57-82.

FRANCE J and THORNLEY JHM. 1984. *Mathematical Models in Agriculture*. Butterworth & Co. Ltd., UK.

HAMMER GL and MUCHOW RC. 1994. Assessing climatic risk to sorghum production in water-limited sub-tropical environments. I. Development and testing of a simulation model. *Field Crops Research*, 36 : 221-234.

HARRINGTON RA and FOWNES JH. 1996. Predicting spacing effects on growth and optimal rotations of tropical multipurpose trees. *Agricultural Systems*, 50 : 377-390.

HODGES T, BOTNER D, SAKAMOTO C and HAUG JH. 1987. Using the CERES-MAIZE model to estimate production for the U.S. Cornbelt. *Agricultural and Forest Meteorology*, 40 : 293-303.

HORIE T. 1988. A model for evaluating climatic productivity and water balance of irrigated rice and its application to Southeast Asia. *Southeast Asian Studies*, 25 : 62-74.

IBSNAT. 1988. *Experimental design and data collection procedures for IBSNAT*. Tech. Rep. 1. 3rd ed. Dept of Agronomy and Soil Science, College of Tropical Agriculture and Human Resources. Univ of Hawaii, Honolulu.

IBSNAT. 1990. *Documentation for IBSNAT crop model input and output files. Version 1.1 for the Decision Support System for Agrotechnology Transfer (DSSAT V2.1)*. IBSNAT Tech. Rep. 5. Dept of Agronomy and Soil Science, College of Tropical Agriculture and Human Resources. Univ of Hawaii, Honolulu.

INMAN-BAMBER NG, CULVERWELL TL and MCGLINCHEY MG. 1993. Predicting yield responses to irrigation of sugarcane from a growth model and field records. *Proc. Sth. Afr. Sug. Technol. Assoc.*, 67 : 66-72.

INMAN-BAMBER NG. 1995. CANEGRO: its history, conceptual basis, present and future uses. In Robertson, M.J. (ed.) *Research and Modelling Approaches to Assess Sugarcane Production Opportunities and Constraints: Workshop Proceedings.* University of Queensland, St Lucia, Brisbane, Australia. 31-34.

JACKSON BS, ARKIN GF and HEARN AB. 1990. *COTTAM: a cotton simulation model for an IBM PC microcomputer*. Misc. Publ., MP-1685, Texas Agricultural Experiment Station, College Station, Texas.

JONES CA and KINIRY JR. 1986. *CERES-Maize: A simulation model of maize growth and development*. Texas A&M University Press, College Station, Texas, USA. 194pp.

JONES CA, WEGENER MK, RUSSELL JS, MCLEOD IM and WILLIAMS JR. 1989. *AUSCANE - Simulation of Australian sugarcane with EPIC, CSIRO Division of Tropical Crops and Pastures Technical Paper No 29,* CSIRO, Australia, Brisbane.

JONES CA., RITCHIE JT, KINIRY JR, GODWIN DC and OTTER SI. 1984. The CERES wheat and maize models. *In* ICRISAT. *Proceedings International Symposium on Minimum Data Sets for Agrotechnology Transfer*. ICRISAT, Patancheru, India. 95-100.

JONES JW. 1993. Decision support system for agricultural development. *In* F.W.T. Penning De Vries et al. eds. *Systems Approaches for Agricultural Development*. Vol 2. Proc. Int. Symp. Bankok, Thailand. Kluwer Academic Press. 459-471.

KEATING BA, ROBERTSON MJ, MUCHOW RC and HUTH NI. 1999. Modelling sugarcane production systems. I. Description and validation of the APSIM sugarcane module. *Field Crops Research*, 61. 253-272.

KINGSTON G. 1994. Benchmarking yield of sugarcane from estimates of crop water use. *Proceedings of the Australian Society of Sugarcane Technologists*, 16 : 201-209.

KROPFF MJ, VAN LAAR HH and MATTHEWS RB. eds. 1994. ORYZA1: an ecophysiological model for irrigated rice production. *SARP Research Proceedings*, AB-DLO/TPE-WAU/IRRI. 110pp.

LESCORRET F, HABIB R, GENARD M, AGOSTINI D and CHADOEUF J. 1998. Pollination and fruit growth model for studying the management of kiwifruit orchards. I. Model description. *Agricultural Systems*, 56 : 67-90.

LITTLEBOY M, SILBURN DN, FREEBAIRN DM, WOODRUFF DR and HAMMER GL. 1989. *PERFECT- A computer model for productivity erosion runoff functions to evaluate conservation techniques*. Queensland Department of Primary Industries, Brisbane , Australia.

LIU DL and KINGSTON G. 1995. A simulation model of sugarcane growth and sugar accumulation: QCANE. *In* Robertson, M.J. ed. *Research and Modelling Approaches to Assess Sugarcane production opportunities and constraints: Workshop Proceedings.* University of Queensland, St Lucia, Brisbane, Australia. 25-30.

LOOMIS RS, NG E and HUNT WF. 1976. PRODUCTIVITY OF ROOT CROPS. IN BURRIS RH. and BLACK CC. eds.. *CO^2 metabolism and the productivity of plants*. Univ. Park Press, Baltimore, MD. 269-286.

MCCOWN RL, HAMMER GL, HARGREAVES JNG, HOLZWORTH DP and FREEBAIRN DM. 1996. APSIM: A novel software system for model development, model testing, and simulation in agricultural systems research. *Agricultural Systems* 50 : 255-271.

MCKINION JM, BAKER DN, WHISLER FD and LAMBERT JR. 1989. Application of the GOSSYM/COMAX system to cotton crop management. *Agricultural Systems*, 51 : 131-146.

MCKINION JM. 1986. MODVEX: A Model Development and Validation Expert system. *American-Society-of-Agricultural-Engineers*. No. 86-4514, 20pp.

MEYER GE and CURRY RB. 1986. Soybean production decision-making with the REALSOY model. *American-Society-of-Agricultural-Engineers*. No. 86-4507, 14pp.

MITCHELL PL. 1997. Misuse of regression for empirical model validation of models. *Agricultural Systems*, 54**:** 313-326.

MOORE AD, DONELLY JR and FREER M. 1997. GRAZPLAN: Decision support systems for Australian grazing enterprises. III. Pasture growth and soil moisture submodels, and the GrassGro decision support. *Agricultural Systems*, 55: 535-582.

MUCHOW RC and CARBERRY PS. 1993a. A simulation model of kenaf for assisting fibre industry planning in Northern Australia. V. Impact of different crop traits. *Australian Journal of Agricultural Research*, 44 : 713-730.

MUCHOW RC and CARBERRY PS. 1993b. Designing improved plant types for the semi-arid tropics: Agronomists' viewpoint. *In* Penning De Vries FWT.et al. (eds.). *Systems Approaches for Agricultural Development*. Vol 2. Proc. Int. Symp., Bangkok, Thailand. Kluwer Academic Press. 37-61.

MUCHOW RC, SINCLAIR TR and BENNET JM. 1990. Temperature, solar radiation and potential maize yield. *Agronomy Journal*, 82 : 338-343.

NEMECEK T, DERRON JO, ROTH O and FISCHLIN A. 1996. Adaptation of a crop growth model and its extension by a tuber size function for use in seed potato forecasting system. *Agricultural Systems*. 52 : 419-438.

NONHEBEL S. 1994. The effects of use of average instead of daily weather data in crop growth simulation models. *Agricultural Systems*, 44 : 377-396.

O'LEARY GJ and CONNOR DJ. 1996. A simulation model of the wheat crop in response to water and nitrogen supply: I: Model construction and II: Model validation. *Agricultural Systems*, 52 : 1-56.

PASSIOURA JB. 1973. Sense and nonsense in crop simulation. *Journal of Australian Institute of Agricultural Science*, 39 : 181-183.

PASSIOURA JB. 1996. Simulation models: science, snake oil, education, or engineering. *Agronomy Journal*, 88 : 690-694.

PLACE RE and BROWN DM. 1987. Modelling corn yields from soil moisture estimates: description, sensitivity analysis and validation. *Agricultural and Forest Meteorology*, 41 : 31-56.

PRESTWIDGE DB, ROBERTSON MJ, MUCHOW RC, HAMMER GL, HUGHES RM, KEATING B., KINGSTON G, LIU DL and WOOD AW. 1994. SUGARBAG: A database system for sugarcane crop growth, climate, soils, and management data. *Tropical Agronomy Technical Memorandum Number 84a*. CSIRO, St Lucia, Brisbane, Australia.

PROBERT ME, DIMES JP, KEATING BA, DALAL RC and STRONG WM. 1998. APSIM's water and nitrogen modules and simulation of the dynamics of water and nitrogen in a fallow. *Agricultural Systems*, 56 : 1-28

ROBERTSON MJ and MUCHOW RC. 1994. Future research challenges for efficient crop water use in sugarcane production. *Proceedings of the Australian Society of Sugarcane Technologists*, 16. 193-200.

ROPOPORT HF and LOOMIS RS. 1986. Structural aspects of root thickening in *Beta vulgaris* L.: Comparative thickening in sugar beet and chard. *Bot. Gaz.*, 147 : 270-277.

ROSENZWEIG C, PHIILIPS J, GOLDBERG R, CARROLL J and HODGES T. 1996. Potential impact of climate change on citrus and potato production in the US. *Agricultural Systems*, 52 : 455-480.

RUSSELL G and VAN GARDINGEN P. 1996. Problems with using models to predict regional crop production. *In* VAN GARDINGEN PR. et al. eds. *Scaling-up*. Cambridge University Press.

SINCLAIR TR and SELIGMAN NG. 1996. Crop modelling: from infancy to maturity. *Agronomy Journal*, 88 : 698-704.

SPEROW M and LYBECKER DW. 1998. Modelling the alfalfa stem nematode in irrigated alfalfa. *Agricultural Systems*, 58 : 555-570.

SPITTERS CJT, VAN KEULEN H and VAN KRAAILINGEN DWG. 1988. A simple but universal crop growth simulation model, SUCROS87. In Rabbinge, R., Van Laar, H. and Ward, S. eds. *Simulation and Systems Management in Crop Protection*. PUDOC, Wageningen. 87-98.

STOCKLE CO and NELSON R. 1994. *Cropping Systems Simulation Model Users' Manual. (version 1.01.00)* Biological Systems Engineering Dept. Washington State University. 167pp.

STOCKLE CO. 1989. Simulation models in agriculture: from cellular level to field scale. *Proceedings of 1989 Summer Conference, Computer Simulation Society*, Austin, Texas, 24-27 July 1989. 639-644.

SUPIT I, HOOIJER AA and VAN DIEPEN CA. eds. 1994. *System description of the WOFOST 6.0 crop simulation model implemented in CGMS. Vol 1. Theory and algorithm* (=EUR 15956), European Commission, Office for official publications of the European Communities, Luxembourg. 146pp.

SWARTZMAN GL and VAN DYNE DM. 1972. An ecologically-based simulation-optimisation approach to natural resource planning. *Annual Review of Ecology and Systematics*, 3 : 347-398.

THOMPSON GD. 1976. Water use by sugarcane. *South African Sugar Journal*, 60. 593-600, 627-635.

THORNLEY JHM and JOHNSON IR. *Plant Growth Modelling: A Mathematical approach to Plant and Crop Physiology*. Oxford Science Publications, Clarendon Press, Oxford, UK. 669pp.

THORNTON PK and HANSEN JW. 1996. A note on regressing real-world data on model output. *Agricultural Systems* 50 : 411-414.

TREBECK DB and HARDAKER JB. 1972. The integrated use of simulation and stochastic programming for whole farm planning under risk. *Australian Journal of Agricultural Economics*, 16 : 115-126.

TSCHESCHKE-P, GILLEY JR; THOMPSON T; FISCHBACH P. 1978. IRRIGATE – a scheduling model. *Agricultural-Engineering*, 59 : 45-46.

TSUJI GY, UEHARA G and BALAS S. eds.. 1994. *DSSAT Version 3. Vol 1. International Benchmark Sites Network for Agrotechnology Transfer*. University of Hawaii, Honolulu.

VAN KEULEN H. 1976. Evaluation of models. *In* Arnold, G.W. and De Wit, C.T. (eds.) *Critical Evaluation of Systems Analysis*.. PUDOC, Netherlands.

VANCLOOSTER M, VIANE P, DIELS J and CHRISTIAENS K. 1994. *Wave: A Mathematical Model for Simulating Water and Agrochemicals in the Soil and Vadose environment* – Reference & User's Manual (Release 2.0). Institute for Land and Water Management, Leuven.

WEGENER MK. 1994. Modelling studies in the Australian sugar industry. Ph.D. Thesis, University of Queensland, Australia.

WILES LJ, KING RP, SCHWEIZER EE, LYBECKER DW and SWINTON SM. 1996. GWM: general weed management model. *Agricultural Systems*, 50 : 355-376.

WILLIAMS JR JONES CA, KINIRY JR. and SPANEL DA. 1989. The EPIC crop growth model. *Transactions of the ASAE*, 32 : 497-511.

WILLIAMS JR, JONES CA and DYKE PT. 1984. A modelling approach to determining the relationship between erosion and soil productivity. *Trans. ASAE*, 27.129-144.

THE SUITABILITY OF SUGAR CANE LANDS FOR TOMATO

S Ramasamy* and *N Govinden

Mauritius Sugar Industry Research Institute

ABSTRACT

In a project initiated in 1984, sugar cane lands have been indexed with respect inter alia to their suitability for the production of potato, maize and groundnut. In the mean time tomato has become the most important vegetable in Mauritius. Since tomato is also grown in association with sugar cane, there was a need to assess the suitability of cane lands for tomato. Based on the suitability of sugar cane lands for potato, maize and groundnut and an analysis of analogies between tomato and these three food crops, a model was prepared to derive the suitability of sugar cane lands for tomato. In order to validate the model, yield was collected and profitability was estimated for 152 commercial tomato plantations in 1995, 1996 and 1998. The model was amended to make the suitability ratings conform more closely to the data gathered from the commercial plantations. The amended model was then used to rate the suitability for tomato of all sugar cane lands in the msiri's land index database. Results show that a higher percentage of sugar cane lands is suitable for tomato in the first season (february – june) than in the second season (july – december) because during the latter season rainfall tends to be insufficient in many localities. Lands belonging to miller- and large-scale planters are generally more suitable for tomato than those belonging to small-scale planters, partly because of irrigation and of improvements such as derocking. Growers can now obtain the suitability for tomato of their cane fields directly from the land index database. This should help in reducing the risk involved in tomato production.

Key words: tomatoes, yields, profitability, modelling, land indexing, land suitability

INTRODUCTION

As from 1984, sugar cane lands were indexed with respect to their suitability for the production of cane, potato, maize and groundnut. The procedure consisted in first ascribing to every cane field physical, edaphic, agroclimatic and agronomic characteristics obtained from maps (Deville and Lim Shin Chong 1984). Then, field visits were made to verify the data. During the field visits, the performance of food crops grown previously on the fields and the physical characteristics likely to influence land suitability were discussed with the owners. Verification of raw data was done from 1982 to 1986 for miller-planters, from 1985 to 1989 for small-scale planters and from 1990 to 1995 for large-scale planters. Finally, the suitability of each sugar cane field for potato, maize and groundnut were assigned for two planting seasons (Govinden and Ramasamy 1994, 1996; MSIRI 1990).

For some time already, the need has been felt to assess the suitability of cane fields for tomato because tomato is also grown in association with sugar cane and has become the most important vegetable in Mauritius. The procedure which was used for the other food crops would have involved too much time and funds. An alternative procedure was therefore used for assessing the suitability for tomato. It consisted of two phases. Phase I was the development of a model. Based on the suitability for potato, maize and groundnut and on analogies between tomato and the three crops, a model was written to derive the suitabilities for tomato. Phase II was the validation of the results of the model with actual field data.

This paper explains the procedure used, discusses its appropriateness and presents the suitability for tomato of sugar cane lands belonging to three categories of planters.

METHODOLOGY

The model for deriving the suitability of lands for tomato was developed in three steps:

Step 1 consisted of the determination of the agro-climatic and edaphic requirements of tomato. Step 2 involved an examination of analogies existing between tomato, on one hand, and potato, maize and groundnut, on the other.

Step 3 was the preparation of a computer programme to derive the suitabilities for tomato.

Sugar cane lands were first grouped by land unit, soil type, slope, rainfall and/or irrigation. Then, based on the analogies, the suitability for tomato was derived for each set of land classes. The suitability classes and sub-classes used for the classification of fields for food crops were those developed by the Expert Consultation on Land Evaluation in Wageningen (Brinkman and Smith 1973), and which were also used in the Land Resources and Agricultural Suitability Map of Mauritius (Arlidge and Wong You Cheong 1973). In this classification, four broad classes are recognized on the existence of limitations to production, expected yield and expected long-term profitability and risks. The limits of each class for food crops under Mauritian conditions have been defined and are presented in **Table 1**

Table 1 Important land suitability classes for food crops in Mauritius

Class	Definition	Profitability and risks
Highly suitable	No limitation	Average profitability ≥ 50% Risks: 2 years out of 10 ≤ 5%
Moderately suitable	One minor limitation	Average profitability = 20 - 50% Risks: 2 years out of 10 ≤ 0%
Marginally suitable	One major limitation or two minor limitations	Average profitability = 5 - 20% Risks: 4 years out of 10 ≤ 0%
Not suitable	Many major limitations	Average profitability < 5% Risks: 6 years out of 10 ≤ 0%

Phase II, the validation of the derived suitability ratings, consisted of the collection of field data on commercial tomato plantations. Validation of ratings for miller-planters' lands was started in 1995 when yield data were collected from 22 fields, since only two miller-planters grew tomato. Since a larger set of data for the major land classes in the main production zones was required, the fields of large and small planters were surveyed in 1996 and 1998. Some additional data were obtained from miller-planters. Over these two years, data were obtained from 152 fields, 41planted in the first season and 111 in the second season.

When the suitability of cane lands for potato, maize and groundnut were determined as from 1984, the sale prices of these commodities were fixed. Consequently, it was possible to associate a mean yield with a given level of profitability and, hence, with a suitability class. But the price of tomato fluctuates considerably during the year, such that a suitability class may not necessarily be associated with a yield, but rather with a revenue level. The average monthly retail prices of tomato on the market in the last 4 years were used to estimate profitability (Appendix 2). The farm-gate prices were assumed to be equal to 50% of the retail prices. Revenue was calculated as the product of yield and average farm gate price. The profitability of each field was estimated as the difference between revenue and cost of production and was expressed as a percentage of cost of production. The latter was assumed to be MUR 65 000 ha^{-1} for highly suitable fields, MUR 60 000 ha^{-1} for moderately suitable fields and MUR 55 000 ha^{-1} for marginally suitable fields (M. Rughoo, *pers. comm.*). Hence, the yield levels needed to achieve a profitability of > 50% for highly suitable fields, of 20 - 50% for moderately suitable fields and of 5 - 20% for marginally suitable fields were computed.

At present, the land index database contains information on miller-, large-scale and small-scale planters' cane lands. For each field, the land unit, soil type, mean annual rainfall and irrigation status are given. A programme has been written to assign to each field its suitability for tomato for the two planting seasons. Areas highly or moderately suitable for tomato for the two planting seasons were then retrieved from the database.

RESULTS

Agroclimatic and edaphic requirements of tomato and analogies with three food crops.

The agroclimatic and edaphic requirements of tomato are summarized in **Table 2**. Tomato thrives in the subhumid and humid zones provided irrigation is available when needed. It does not thrive in the superhumid zone because of diseases and soil acidity. Groundnut and maize have similar characteristics.

Table 2 Summary of agroclimatic and edaphic requirements of tomato and analogies with potato, maize and groundnut

	Requirements	Analogies with other crops
Agroclimate	Sub humid and humid zones (provided irrigation is available when needed)	Analogous to maize; groundnut needs less, and potato needs more water
Soil	Light, deep to moderately deep, well drained and fertile.	Analogous to maize; groundnut prefers lighter, and potato heavier soils.
	Neutral to slightly acidic (pH: 5.5 – 7.0)	Analogous to maize; groundnut prefers slightly basic to neutral, and potato prefers slightly acidic soils
Ease of cultivation	Easy to moderate	Analogous to maize; groundnut and potato need land which are easy to cultivate.
Planting dates	*1st season:* February – June	Overlaps partly with groundnut (Feb – Mar), partly with maize (Mar-April), and partly with potato (April-June).
	2nd season: July - December	Overlaps partly with maize and potato (Aug-Sep) and partly with groundnut (Sep-Dec).
Crop cycle	4 ½– 5 months when transplanted	Same as full-season maize; longer than groundnut (4 - 4½months) and potato (3 months).

The edaphic requirements of tomato in these favoured zones are similar to those of maize, that is, all soil types are suitable as long as drainage is not a problem.

Tomato can be grown all year round, but because of the risks of cyclones, two planting seasons can be defined, as for potato, maize and groundnut. During the first season, the planting period of tomato extends from February to June and overlaps partly with that of maize, of groundnut and of potato. The second season extends from July to December and overlaps partly with that of the other three crops.

The model to derive suitability ratings for tomato

The model for deriving suitabilities for tomato in two planting seasons as a function of land units, soil types and rainfall or irrigation regimes is presented in **Table 3**.

Table 3 Model for deriving the suitability ratings of tomato as a function of land units, soil types and rainfall ranges

Land Units	Soil Type †	Rainfall range *mm*	Suitability ratings *	
			1st season	*2nd season*
1.1, 1.2, 1.4,.2.1, 2.2, 3.1, 5.1, 5.2, 6.1	P,L,H,B	Irrigated	100	100
		< 1350	310	410
		1351 -1500	210	410
		1501 - 1800	100	410
		1801 - 2100	100	310
		2101 - 2500	100	210
		2501 - 3200	220	100
		> 3200	320	220
2.3, 3.2, 6.2, 10.1	L,P.H	Irrigated	260	260
		≤ 005,1	316	516
		1501 - 1800	260	516
		1801 - 2500	260	316
		2501 - 3200	326	260
		> 3200	0	326
1.3, 1.5, 2.4, 3.3, 4.1, 5.3, 5.4, 6.3, 13.1	P,B,F,D,C	Irrigated	230	230
		≤ 005,1	313	513
		1501 – 1800	230	513
		1801 – 2500	230	313
		2501 – 3200	323	230
		> 3200	0	323
3.4, 6.4	F	2500 – 3200	323	336
		> 3200	0	323
1.6, 3.5, 5.5, 5.6, 6.5, 10.2, 10.3, 10.4, 11.1, 12.1	F,T,D			

† P – Latosolic Reddish Prairie
L – Low Humic Latosols
H – Humic Latosols
B – Latosolic Brown Forest
F – Humic Ferriginous Latosols
D – Grey Hydromorphic
T – Lithosols
C – Regosols

* The first digit is the suitability class and the next two digits represent limitations in order of decreasing importance as shown below:

Suitability class (1st digit)

1. Highly suitable
2. Moderately suitable
3. Marginally suitable
4. Conditionally highly suitable
5. Conditionally moderately suitable
0. Not suitable

Limitations (2nd & 3rd digits)

1. Seasonally dry conditions
2. High rainfall and low evaporation
3. Unfavourable soil conditions (depth, texture)
6. Adverse slope conditions

Validation of suitability ratings assigned by the model

Fields under rainfed conditions (Non-irrigated).

The yield and profitability of 52 non-irrigated tomato fields, 3 planted in the first season and the rest planted in the second season are presented in **Table 4**. The three fields planted in the first season were all rated as highly suitable and their performance confirmed the derived ratings (**Table 4**).

Table 4 Yield and average profitability of non-irrigated tomato fields

Land Unit	Rainfall Range *mm*	Planting period	No. of fields	Average Yield *t ha^{-1}*	Average profitability *%*	Derived suitability rating †
(a) First season plantations						
3.1	1801 - 2100	Mar - Apr	3	17.3 ± 1.3	95	100
(b) Second season plantations						
3.1	2501 - 3200	July - Aug	3	16.9 ± 1.3	> 100	100
1.5	2501 - 3200	Aug - Sept	3	10.2 ± 0.8	26	230
3.1	2101 - 2500	July - Sept	5	10.8 ± 2.7	35	210
5.3	2501 - 3200	July	1	6.0	- 15	230
5.4	2501 - 3200	July - Sept	13	12.6 ± 2.8	52	230
	2501 - 3200	October	2	18.7 ± 1.0	> 100	230
6.1	1801 - 2100	October	2	7.7 ± 0.5	30	210
1.5	2101 - 2500	July - Sept	7	7.9 ± 3.2	8	313
3.5	2101 - 2500	July - Aug	3	7.1 ± 1.7	5	313
	> 3200	July - Sept	7	6.8 ± 2.1	-7	313
6.3	2101 - 2500	Aug - Sept	3	7.8 ± 2.0	5	313

† Rating codes as in table 2

In the second season also, the 3 fields rated as highly suitable for tomato performed as expected, but only 10 out of the 26 fields rated by the model as moderately suitable gave profitabilities within the expected range of 20 – 50%. The yields of these fields were on average 11.6 t ha^{-1} for plantations made in July to September and 7.6 t ha^{-1} for plantations made in October. Fifteen of the fields rated as moderately suitable (all in land unit 5.4) yielded on average 13.4 t ha^{-1} and gave a profitability of more than 50%, while a loss was incurred from a field (land unit 5.3) also rated as moderately suitable. The average yield of the 20 fields rated as marginally suitable was 7.3 t ha^{-1} and the average profitability in all cases was less than 20%, as expected.

Fields irrigated occasionally with watering cans

Fields irrigated occasionally with watering cans were assigned ratings one class above their ratings under rain fed conditions. For instance, a field rated as marginally suitable (310) was rated as moderately suitable (210) if it was irrigated with watering cans. This is because irrigation with watering cans is practised by growers only during dry spells and because the amount of water applied is much less than in the crop's requirement.**Table 5.**

Yields were obtained from 14 fields planted in the 1st season. The six fields rated as highly suitable yielded on average 12.6 t ha^{-1} and gave, as expected, an average profitability of more than 50%. The eight other fields rated as moderately suitable gave an average yield of 9.7 t ha^{-1} and an average profitability of more than 20%, as expected.

In the second season, the yield and profitability of the 5 fields rated as highly suitable and of 12 out of the 17 fields rated as moderately suitable were within expected ranges. The remaining 5 fields (4 in land unit 5.4 and 1 in land unit 1.5) rated as moderately suitable gave average profitabilities of more than 50%. As expected, the profitability of the 16 fields rated as marginally suitable for tomato was less than 20% and the average yield was 8.0 t ha^{-1}

Table 5 Yield and profitability of fields irrigated occasionally with watering cans.

Land Unit	Rainfall Range *Mm*	Planting period	No. of fields	Average Yield *t ha^{-1}*	Average profitability *%*	Derived suitability rating †
1st season plantations						
1.4	2100 - 2500	Apr - June	6	12.6 ± 2.7	51	100
1.5	1801 - 2100	Apr - June	3	10.1 ± 1.3	38	230
13.1	1351 - 1500	May - June	5	9.8 ± 2.2	23	210
2nd season plantations						
3.1	2101 - 2500	Aug - Sept	5	12.1 ± 1.8	57	100
1.5	1801 - 2100	October	1	13.8	> 100	230
3.1	1801 - 2100	Aug - Sept	8	10.1 ± 1.9	22	210
5.4	2501 - 3200	July - Aug	4	16.5 ± 2.5	> 100	230
13.1	1801 - 2100	Aug - Sept	4	11.1 ± 1.2	40	210
1.1	1351 - 1500	July - Aug	2	7.7 ± 0.8	18	310
1.4	1501 – 1800	July - Aug	4	7.9 ± 2.3	15	310
1.5	1501 – 1800	July - Sept	8	8.2 ± 1.8	18	313
2.1	1351 - 1500	July - Aug	2	7.5 ± 1.1	16	310

† Rating codes as in table

Fields irrigated regularly by overhead, surface, drip and pivot systems

Fields irrigated regularly with overhead, surface, drip and pivot systems were rated as highly suitable for tomato if no edaphic or climatic constraint was present, and as moderately suitable if one constraint was present. In the first and second seasons, 39 of the 43 fields rated as highly suitable for tomato gave a profitability of more than 50% (**Table 6**). Losses were incurred from two fields planted in January and which were affected by bad weather and from one field planted in April due to an unexpected drop in price. In the first season, the two fields rated as moderately suitable performed as expected, while in the second season the 3 fields (land unit 1.5) rated as moderately suitable performed better than expected.

Expected yields

The expected yields from fields rated as highly, moderately and marginally suitable for tomato for different planting dates are summarized in **Table 7.** .

These expected yields have been computed by using the average farm-gate price of tomato for the corresponding planting dates and the profitability range required for each suitability class. For plantations made in the period December – January, yield as low as 6.0 t/ha can generate profits of at least 50%. The farm-gate prices obtained for plantations made in this period are always high (**Table 8**) because few growers cultivate tomato.

A much higher yield (average 12.5 t/ha) is necessary for fields planted in the period April to December to generate the same level of profit. During this period production is high and prices are low because cane lands are available for planting and the weather is conducive to tomato growth and development

Table 6 Yield and profitability of regularly irrigated tomato fields.

Land Unit	Rainfall Range *mm*	Planting period	No of fields	Average yield *t ha^{-1}*	Average profitability *%*	Assigned suitability rating
1st season plantations						
1.4	1351 - 1500	Mar - June	9	16.2 ± 3.2	85	100
2.1	1351 - 1500	January	1	20.4	> 100	100
	1351 - 1500	January	1	2.3	-10	100
	1351 - 1500	Feb - Mar	4	19.3 ± 1.8	> 100	100
	1351 - 1500	Apr - June	5	18.9 ± 2.1	>100	100
6.1	1501 - 1800	January	1	2.3	-13	100
	1501 - 1800	April	1	7.0	-25	100
1.5	1501 - 1800	May - June	2	9.5 ± 1.1	25	230
2nd season plantations						
1.4	1351 - 1500	Aug - Sept	3	16.7 ± 1.7	> 100	100
2.1	1351 - 1500	July - Sept	7	16.8 ± 2.2	> 100	100
	1351 - 1500	Oct - Dec	6	13.3 ± 1.7	> 100	100
2.2	1351 - 1500	July	1	10.3	28	100
3.1	1501 - 1800	Aug - Sept	2	16.5 ± 0.9	> 100	100
	1801 - 2100	August	2	23.5 ± 1.8	100	100
1.5	1501 - 1800	August	2	16.5 ± 0.7	> 100	230
	1801 - 2100	October	1	21.8	> 100	230

Table 7 Expected yields and % of fields confirming ratings derived by the model.

	Highly suitable fields		Moderately suitable fields		Marginally suitable fields	
	Expected Yield *t ha^{-1}*	Fields within range *%*	Expected Yield *t ha^{-1}*	Fields within range *%*	Expected Yield *t ha^{-1}*	Fields within range *%*
1st season						
January	> 5.6	33	4.1 – 5.1	-	3.3 – 3.8	-
Feb – Mar	> 8.7	83	6.4 – 8.0	-	5.1 – 5.9	-
Apr – June	> 12.2	95	9.0 – 11.8	100	7.2 – 8.3	-
Average		87		100		-
2nd season						
July – Sept	> 13.0	96	9.6 – 12.0	50	7.7 – 8.8	81
Oct – Nov	> 8.9	100	6.9 – 8.5	33	5.5 – 6.3	-
December	> 6.5	100	4.8 – 6.0	-	3.9 – 4.4	-
Average		97		48		81
Average both seasons		**92**		**57**		**81**

Table 8 Retail prices of tomato (Means of 1995, 1996, 1997 and 1998)

Planting month	Harvest period	Retail price *MUR kg^{-1}*
January	Mar – Apr	40
February	Apr – May	25
March	May – Jun	20
April	Jun – Jul	16
May	Jul – Aug	14
June	Aug – Sep	16
July	Sep – Oct	17
August	Oct – Nov	15
September	Nov – Dec	14
October	Dec – Jan	20
November	Jan – Feb	22
December	Feb – Mar	32

During the years 1995, 1996 and 1998, yield data were obtained from 41 fields planted in the 1st season. The model rated thirty-one fields as highly suitable for tomato and the remaining fields as moderately suitable. The yield and profitability of 87% of the highly suitable fields and of all the moderately suitable fields confirmed the ratings given by the model (**Table 7**).

In the 2nd season, yield data were obtained from 111 fields. Ninety seven percent of the highly suitable fields gave the expected yield and profitability (**Table 7**). For moderately suitable fields the expected performance was obtained from only 48% of the fields. This is because most of the fields within the land unit 5.4 and given as moderately suitable by the model performed better than expected. The model must therefore be amended to make it conform more closely to the data.

Of the 36 fields rated as marginally suitable for tomato, 29 (81%) performed as expected, that is, they gave profitabilities between 5 and 20%. Losses were incurred from the remaining 7 fields, which confirmed the high risks involved when cultivating fields classified as marginal.

DISCUSSION

Field validation of the model show that the rating of highly suitable assigned by the model to fields in the 1st and 2nd seasons was generally valid. Overall, 92% of the fields confirmed the ratings assigned (**Table 7**). These fields were within three main land units: 1.4, 2.1 and 3.1.

Fields within land unit 5.4 and rated as moderately suitable for tomato performed better than expected. The profitability obtained from these fields was higher than 50%. Consequently, the model has been amended for this land unit by upgrading the rating. The other fields within 4 major land units: 1.5, 3.1, 6.1 and 13.1 and rated as moderately suitable for tomato confirmed the rating given by the model.

The percentage area highly or moderately suitable for tomato varies with season and is different for the three planter categories (**Table 9**). Similar observations were made on the suitability of sugar cane lands for potato, maize and groundnut (Ramasamy and Govinden 1999), and the same reasons apply.

For each planter category, the area that is suitable for tomato is less in the second season because rainfall tends to be insufficient in some localities. The miller-planters have the highest percentage of land which are either highly suitable or moderately suitable for tomato and the small-scale planters have the least percentage. This is due to the fact that for historical reasons, the small-scale planters and some large-scale planters possess or have inherited a higher proportion of the marginal lands of Mauritius than the miller-planters or other large-scale planters.

Also, the small-scale planters have less irrigation and have not improved their lands to the same extent as the other planter categories.

Islandwise, only about 56% of small-scale planters' cane lands receive irrigation (MSIRI 1990), compared to about 25% of miller-planters' cane lands (MSIRI 1996).

Table 9 Suitability for tomato of sugar cane lands belonging to three planter categories

Zone	Area highly and moderately suitable for tomato as % of total					
	Miller-planters		Large-scale planters		Small-scale planters	
	Season					
	1st	*2nd*	*1st*	*2nd*	*1st*	*2nd*
North	88.3	29.9	68.9	22.4	38.1	2.2
East	55.6	34.5	49.5	32.3	33.4	21.5
Centre	68.7	79.1	59.1	29.2	52.6	31.6
West	94.7	89.7	88.8	80.7	35.9	1.0
South	66.3	61.5	37.7	16.8	53.2	34.2
Island	70.7	53.5	50.6	34.5	42.3	19.6

In the West, most of the miller-planters' and large-scale planters' cane lands are either highly or moderately suitable for tomato in both seasons because of extensive irrigation and adequate derocking. Most of the small-scale planters do not have irrigation such that the percentage of cane lands which is either highly or moderately suitable for tomato is low, especially in the second season when rainfall is deficient.

About 24% of growers have been cultivating tomato on lands rated as marginally suitable. The profit obtained from these fields was indeed very low. Losses were incurred from 7 out of 36 fields. This shows how important it is to determine the suitability of lands for tomato and to communicate the information to the agricultural community. Examples of listings for miller-planters', large-scale planters' and small-scale planters' cane lands are given in **Table 10**.

These listings should be useful tools for tomato growers who can now read the potential of their fields and estimate the risk involved in cultivating tomato. The possibility of preparing a suitability map for tomato is being examined.

Table 10 Examples of listings of suitabilities of sugar cane fields for potato, maize, groundnut and Tomato

Land Suitability rating																
Field No.	Area *ha*	Irrigation	Soil Type & Phase	Slope	Rain *mm*	Evaporation *mm*	Altitude *m*	Land Unit	Potato 1	Maize 1	G/nut 1	Tomato 1	Potato 2	Maize 2	G/nut2	Tomato 2
Miller planter: Beau Plan (Section: Maison Blanche)																
1	5.93	NONE	P2 G	FLAT	1650	1805	107	1.1	210	100	100	100	410	410	410	410
2	6.35				1650	1805	104	1.1	210	100	100	100	410	410	410	410
3	4.72				1625	1805	107	1.1	210	100	100	100	410	410	410	410
4	4.84				1625	1805	114	1.1	210	100	100	100	410	410	410	410
5	3.01		P2 R		1625	1810	122	1.4	313	230	230	100	513	513	513	410
6	5.95				1625	1810	125	1.4	313	230	230	100	513	513	513	410
7	6.42				1600	1810	116	1.4	313	313	230	100	513	513	513	410
8	3.48				1575	1810	122	1.4	313	313	230	100	513	513	513	410
10	10.9				1600	1810	128	1.4	313	313	230	100	513	513	513	410
11	3.68				1600	1810	130	1.4	313	313	230	100	513	513	513	410
Large planter: Belle Isle (Factory Area: Medine)																
5	2.46	Surface	P / L N	FLAT	950	1825	365	2.1	100	100	100	100	100	100	100	100
6	1.66				950	1825	350	2.1	100	100	100	100	100	100	100	100
7	2.53				950	1825	350	2.2	100	100	100	100	100	100	100	100
8	3.17				950	1825	350	2.2	100	100	100	100	100	100	100	100
9	1.14				950	1825	340	2.2	100	100	100	100	100	100	100	100
10	0.77				950	1825	340	2.2	100	100	100	100	100	100	100	100
Small planter: Factory Area FUEL (Locality J - 2 - 4)																
* 8219	0.12	NONE	H2 N	FLAT	2300	1550	168	3.1	100	100	100	100	310	310	310	310
80563	0.15				2300	1550	168	3.1	100	100	100	100	310	310	310	310
4445	0.18				2300	1550	168	3.1	100	100	100	100	100	100	100	100
2981	0.16		B1 VR		2300	1550	168	1.5	335	230	335	230	513	513	513	513
80604	0.20				2300	1550	168	1.5	335	230	335	230	513	513	513	513
1737	0.20				2300	1550	168	1.5	335	230	335	230	513	513	513	513

* SIFB account number

CONCLUSION

A model has been prepared to derive the suitability of sugar cane lands for tomato from the suitability for other food crops. Validation of the model was complicated by fluctuations in the price of tomato. In contrast to other crops in the land index database, no fixed yield level can be given for the different suitability classes for tomato. Instead, yield levels have been set as a function of planting dates. The model has first been validated and then amended to make it conform as closely as possible to data gathered from commercial plantations. The findings confirm the appropriateness of the methodology used to determine the suitability of lands for tomato. A similar approach can be used for other crops.

ACKNOWLEDGEMENTS

We acknowledge Sugar Estate Agronomists and all tomato planters who provided yield data, Miss S Jahmeerbacus of the Biometry Department for compilation of data and preparation of listings from the land index database, and Mr. M. Rughoo for cost of production figures.

REFERENCES

ARLIDGE EZ and WONG YOU CHEONG Y. 1973. *Notes on the land suitability map of Mauritius, 1:50 000*. MSIRI Occasional Paper No. 29. Réduit, Mauritius Sugar Industry Research Institute.

BRICKMAN R and SMITH AJ. eds. 1973. *Land evaluation for rural purposes: a summary of an expert consultation*, Netherlands, 1972. Publication No.17. Wageningen, International Institute for Land Reclamation and Improvement.

DEVILLE J and LIM SHIN CHONG J. 1984. Statistics of sugar cane lands in Mauritius and their utilisation. *Proceedings of FAO workshop: Development of a system of current agricultural statistics*. Réduit, University of Mauritius.

GOVINDEN N and RAMASAMY S. 1994. Indexing of sugar cane lands in Mauritius. I. Food crop suitability and production potential of miller-planters' lands. *Revue Agricole et Sucrière de Ile Maurice* 73 (3): 11-20.

GOVINDEN N and RAMASAMY S. 1996. Indexing of sugar cane lands in Mauritius. III. Food crop suitability and production potential of large-scale planters' lands. *Revue Agricole et Sucrière de Ile Maurice* 75 (1): 37-45.

MSIRI *see under* Mauritius Sugar Industry Research Institute.

MAURITIUS SUGAR INDUSTRY RESEARCH INSTITUTE. 1990. *The land index project for small planters*. Occasional Report No. 4.. Réduit, Mauritius Sugar Industry Research Institute. 45pp.

MAURITIUS SUGAR INDUSTRY RESEARCH INSTITUTE. 1996. Sugar cane. *Ann. Rep. Maurit. Sugar Ind. Res. Inst*. 1995 42. Réduit, Mauritius Sugar Industry Research Institute.

RAMASAMY S and GOVINDEN N. 1999. The suitability and production potential for three food crops of sugar cane lands belonging to three planter categories. [Submitted to Revue Agricole et Sucrière de Ile Maurice *in press*].

PERFORMANCE OF CHOPPER HARVESTERS AND THEIR EFFECTS ON SOIL AND CROP AT BEAU CHAMP SUGAR ESTATE

V Rivière, C Marot, R Ng Cheong **and** *E Jacquin*

Mauritius Sugar Industry Research Institute

ABSTRACT

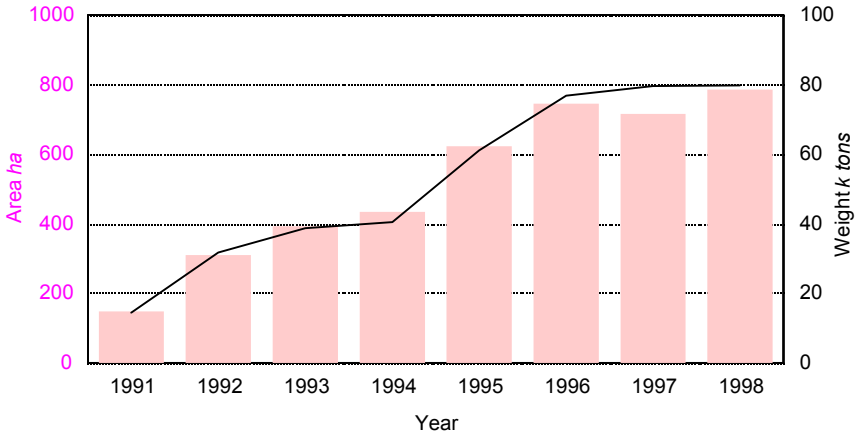
Beau Champ estate was affected by agricultural labour shortage at the end of the 1980's. Two chopper harvesters were purchased and are presently harvesting about 80 000 tonnes annually. Their performance are reviewed and discussed. Results of a trial set up to assess the effect of mechanized harvesting on soil and crop at Beau Champ are also discussed.

Keywords: sugarcane, mechanisation, harvest, chopper harvesters, yields, soil physical properties, compaction, dry bulk density, software

INTRODUCTION

After a first attempt in the mid 1970's, mechanical harvesting of sugar cane was once more introduced at Beau Champ Sugar Estate in the early 1990's. Like many other estates at that period, Beau Champ was faced with an increase in the wages of agricultural labour and a shortage of seasonal labour normally hired for cane cutting. After having tried the two types of machines (whole-stalk and chopper harvester) belonging to a contractor, the choice was made to purchase a chopper harvester in 1991.

Figure 1 Trend in chopper harvesting at Beau Champ



Land preparation to allow mechanization was carried out (mainly derocking and levelling) and the area suitable for mechanized harvesting was such that in 1995, a second chopper harvester was acquired. The amount of cane harvested mechanically by chopper harvesters has increased regularly across the years to reach 80 000 tonnes (24.3 % of the estate's total cane production) in 1998(**Figure 1**). The two main cane varieties harvested mechanically are R 570 (34 %) and M 695/69 (33 %)**.** This paper highlights the performance of the chopper harvester at Beau Champ and its effect on cane yield and soil physical properties.

HARVESTER PERFORMANCE

As mechanical harvesting had just been introduced in the island, information on harvesting sites and parameters affecting harvester performance had to be gathered. Computer software, MECABASE, was devised by the Biometry Department of the Mauritius Sugar Industry Research Institute (MSIRI) in 1990. Beau Champ was one of the three estates utilizing the software which requires the presence of one full-time employee daily on the harvesting site to note down the following parameters: area and weight harvested, hours of operation, various downtimes namely mechanical breakdown, field downtime (changing of base cutter and chopper blades) and harvester waiting time due to lack of transport units and soil moisture. The data collected are then fed into the software to generate harvester performance on a daily basis. Weekly and monthly summaries are also available from the software.

Data on harvester performance on the three main sections where mechanized harvesting is practiced at Beau Champ, extracted from MECABASE between 1991 and 1994, are given in **Tables 1 and 2**.

Table 1 Harvester performance at Beau Champ 1991 - 1992

	Unit	1991				1992			
		Trois Ilots	Olivia	Deep River	Estate	Trois Ilots	Olivia	Deep River	Estate
Area	*ha*	16.8	64.3	67.3	148.4	51.4	118.0	117.3	286.7
Weight	*t*	1 351	6 556	6 473	14 381	5 358	11 800	11 855	29 013
Field hours	*h*	66.8	197.6	241.1	505.5	174.6	356.3	378.7	909.6
Overall output	$t\ ha^{-1}$	20.2	33.2	26.9	28.5	30.7	33.1	31.3	31.9
Field breakdown	*%*	5.4	3.5	12.9	8.2	7.7	5.3	11.8	8.5
Mech breakdown	*%*	4.6	2.2	2.7	2.7	4.6	3.6	3.2	3.6
Waiting time	*%*	21.1	21.3	13.3	17.5	20.3	15.7	11.9	15.0
Effective output	$t\ ha^{-1}$	29.4	45.4	37.8	39.8	45.6	43.9	42.8	43.8

Overall harvester output refers to the cutting rate taking into account both productive and unproductive times (downtimes) of the harvester. On the other hand, effective harvester output refers to the cutting rate with downtimes being excluded.

Table 2 Harvester performance at Beau Champ 1993 - 1994

	Unit	1993				1994			
		Trois Ilots	Olivia	Deep River	Estate	Trois Ilots	Olivia	Deep River	Estate
Area	*ha*	62.4	165.4	151.1	378.9	94.7	114.7	190.4	399.8
Weight	*t*	6 423	15 976	14 393	36 792	9 826	9 176	18 036	37 038
Field hours	*h*	188.6	467.5	405.6	1061.7	304.2	281.2	568.8	1154.2
Overall output	$t\ ha^{-1}$	34.1	34.2	35.5	34.7	32.3	32.6	31.7	32.1
Field breakdown	*%*	4.7	4.6	7.8	5.8	3.7	4.3	8.1	6.0
Mech breakdown	*%*	3.5	5.9	5.0	5.1	6.1	6.9	5.8	6.2
Waiting time	*%*	12.5	10.7	5.3	8.9	14.7	6.5	10.7	10.7
Effective output	$t\ ha^{-1}$	42.9	43.3	43.4	43.3	42.8	39.6	42.1	41.6

Generally an increase in the overall harvester output is observed over time, except for 1994 where cane yield was affected by a severe cyclone. Several factors are responsible for this increase. Over the years harvester operators have acquired experience and knowledge of the harvesting sites of the estate so that they are able to operate the machine at higher speeds thereby increasing the amount of cane cut per unit

time of operation. In addition, harvesting efficiency has increased due to longer cane rows having been planted, as recommended (MSIRI 1991).

The same trend is observed for effective harvester output. The percentage downtimes from 1991 to 1994 have been reduced from 28.4 % to 22.9 % with a more significant reduction in 1993 (19.9 %). Different trends are shown after partitioning of these downtimes (**Tables 1** and **2**). Field downtime due to change of base cutter and chopper has decreased showing that the continuing practice of stone and rock removal from fields was a judicious decision. However, mechanical breakdown has increased steadily over the years as harvesters become more prone to breakdown with time. A strict maintenance schedule is kept at Beau Champ S.E. Every morning a thorough check up is performed before the harvester starts operating in order to minimise the risk of important breakdowns.

Harvester waiting time has been reduced over the years. This is due to a significant investment policy on transport units from the field edge to the mill. In 1991and 1992 there were only six tractor-drawn rear tipper trailers (12 tonnes capacity) operating on the estate. In case of mill breakdowns or traffic jams in the mill yard, these trailers did not return in time to the harvesting site causing stoppages. As from 1993, rear tipper trailers with greater payloads (between 18 and 20 tonnes), drawn either by lorries or fast tractors, were introduced gradually to replace the smaller units so as to decrease harvester-waiting time. In 1998 eleven such trailers were used during the harvesting season. The 12-tonne units are used as spares whenever there is a need on the harvesting site. The software was not designed to distinguish between lack of transport units and soil conditions. The proportion of downtime due to soil conditions is more significant than lack of transport units especially in the wet winter months of July to September. Harvester efficiency has increased still further since 1995, e.g. in 1997, one machine harvested 714 tonnes of cane in twelve hours.

MECABASE has allowed the estate personnel to identify the various causes of harvester downtime and fields where the daily output was low (slope, field and road not at same level). Remedial actions have been taken so that when a second harvester was purchased in 1995, there was no longer need for the same type of follow up which, as stated earlier, requires one full time employee.

EFFECTS OF CHOPPER HARVESTING ON CANE YIELD AND SOIL PHYSICAL PROPERTIES

From the onset of mechanized harvesting, cane growers have expressed concern about compaction and associated effects (decrease in porosity and lowering of infiltration rates) caused by chopper harvesters and in-field transport. Traffic-induced compaction has been found either to reduce yields **(**Swinford and Boevey 1984**)** or to have no effect **(**De Beer et al. 1993**)**. As sugar cane is ratooned for at least 7 years, there may be a long-term cumulative effect of traffic-induced compaction in the interrows. In this context, in 1993 a trial was initiated at Beau Champ in plant cane (variety R 570, burnt) to assess whether cane yields and soil properties were affected with the traffic of chopper harvester in fields.

The experimental site was situated at Deep River section at an altitude of 114 m with a mean annual rainfall of 2400 mm. The soil belongs to the Humic Latosol group **(**Parish and Feillafé 1965**)**. The treatments applied were manual harvesting followed by mechanical in field loading and mechanized harvesting with a chopper harvester accompanied by infield loaders. The trial design was a randomised block with 8 replicates.

Dry bulk density was considered the most appropriate parameter for assessing compaction. The gamma-neutron probe (MC-S-24 model) was chosen for reliability of results with little soil disturbance **(**Soane et al 1981**)**. This equipment, which has been calibrated under local conditions, records soil volumetric moisture content and wet bulk density. Dry bulk density is computed by difference. Readings were taken at 10, 20 and 30 cm depths on a monthly basis both in these cane rows and interrows.

Effect on cane yield

Table 3 presents cane yields from the two treatments from 1994 (1st ratoon) to 1997 (5th ratoon). As from the 3rd ratoon, the amount of extraneous matter was also determined and the clean cane yield calculated.

Table 3 Cane yield at harvest *t ha*$^{-1}$

Year	Total cane yield			Clean cane yield		
	Manual harvest	Mechanized harvest	L.S.D p = 0.05	Manual harvest	Mechanized harvest	L.S.D p = 0.05
1994	83.2	82.8	3.2	-	-	-
1995	93.3	103.6	7.1	88.9	92.6	6.5
1996	96.5	106.3	7.5	88.7	88.4	6.5
1997	104.1	106.5	5.1	96.8	92.7	4.6
Mean	94.3	99.8	8.5	91.4	91.2	9.7

Total cane yields in the mechanized treatment were higher in all years, except 1994, which was a cyclonic year. Significant differences were observed in 1995 and 1996 but when extraneous matter was excluded, both treatments were comparable. It is to be noted that unavoidable losses, namely through the fan extractors of the harvester have not been considered. Previous studies have shown that 1-2 tonnes of cane per hectare may be lost through the cleaning device of the harvester. The above data indicate that chopper harvesting does not affect adversely cane yield.

Effect on soil physical properties

Dry bulk density results are presented in **Figures 2**and **3** for the cane rows and interrows respectively from the 2nd to the 4th ratoon. For each harvest the graphs show the bulk density status before harvest, immediately after harvest and just before the next harvest.

An increase in dry bulk density was observed in both the cane rows and interrows. The increase was more obvious in second and third ratoons. In the second ratoon, bulk density in the cane rows increased to a similar extent in both treatments. However in the third ratoon, a larger increase was observed in the mechanized harvest plots. For the interrows, increase in bulk density was equally important for both treatments especially in the second and third ratoons. This indicates that cane rows and interrows are compacted by both the harvester and the mechanical loader confirming the cane yield results above.

The most noticeable change in bulk density was observed at 10 cm depth with little change at 30 cm. Similarly Torres et al (1990**)** observed that compaction was mostly confined to the shallower part of the soil profile. Bulk density decreased with time and this change was most obvious at 10 cm. The compaction effect at shallow depths is therefore not permanent. Since no decompaction measures were taken, this phenomenon may be the result of natural processes occuring in the soil namely microorganism activity, root development as well as wetting and drying. The soil structure is modified by these processes with formation of new pores and enlargement of existing ones causing the bulk density to decrease between each harvest

Figure 2 Dry bulk density in cane rows g cm^{-3}

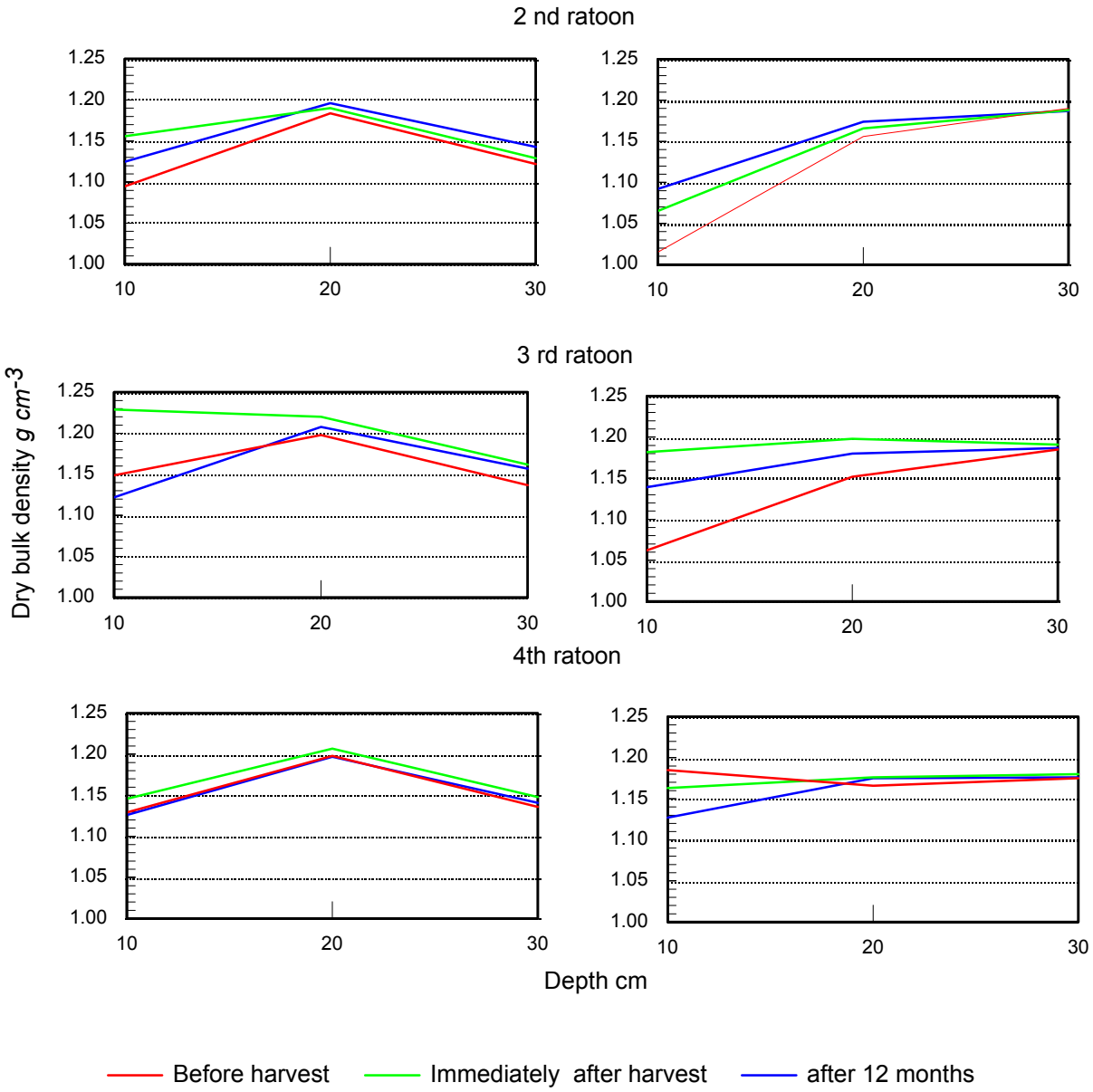
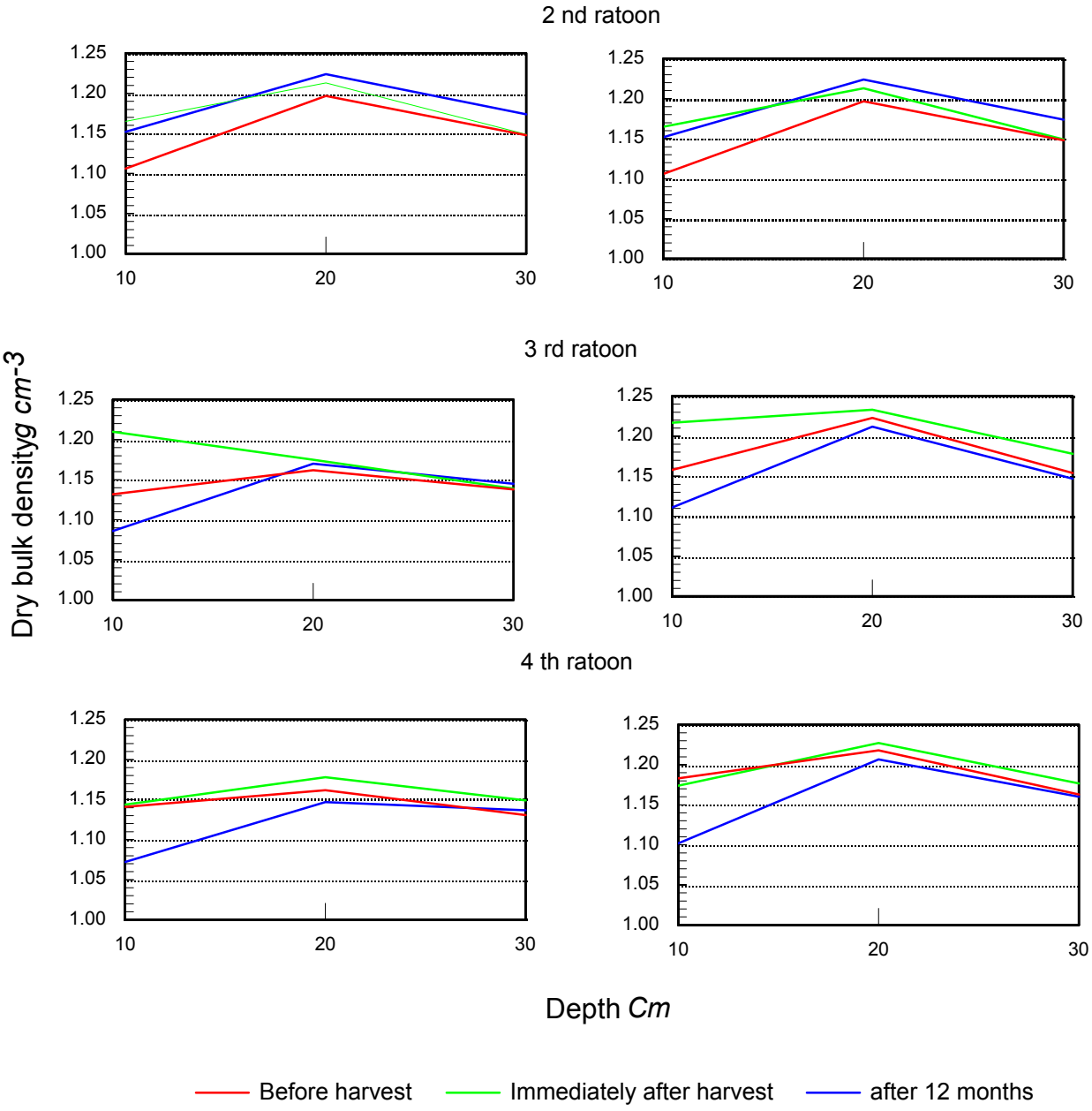


Figure 3 Dry bulk density in cane interrows g cm^{-3}



Future development

The area under mechanized harvesting at Beau Champ S.E has followed an increasing trend since 1991 with a field planning and layout programme. **Table 4** summarizes the extent of the area under mechanized harvesting for the different sections in 1991 and 1998 and the target aimed by the year 2005. It is observed that in 1998 more than 90 % of the areas targeted have been reached at Olivia, Trois Ilots and Deep River. Ferney section is being developed at a fast rate. This has been possible since Ferney, as well as Olivia, Deep River and Trois Ilots, have a relatively rock-free soil.

Further developments will depend on the availability of funds and on the acreage being prepared to allow mechanization.

Table 4 Trend in the area harvested mechanically

Estate Sections	Area under cane *ha*	Area under mechanical harvesting *ha*			% achieved in 1998
		1991	1998	2005	
Deep River	171	17	129	135	95.6
Olivia	324	64	299	306	97.7
Trois Ilots	324	67	260	285	91.2
Ferney	936	-	232	510	45.4
La Lucie	347	-	36	250	14.4

CONCLUSIONS

MECABASE has proved to be a very useful tool in the improvement of mechanical harvesting sites and harvester performance. Mechanical harvesting under experimental conditions does not affect cane yield. Change in soil physical properties resulting from the passage of chopper harvesters and accompanying in-field transport does not affect yield. Chopper harvesters are a successful substitute to manual cane cutting at Beau Champ.

ACKNOWLEDGEMENTS

The authors wish to thank the Director of the Mauritius Sugar Industry Research Institute for his permission to publish this work. Grateful thanks are also due to the staff of Beau Champ S.E for their help.

REFERENCES

DE BEER G, HUDSON JC, MEYER E and TORRES JS. 1993 . Cost effective mechanization. *Sugar Cane* (4) : 11 - 16.

MSIRI *see under* MAURITIUS SUGAR INDUSTRY RESEARCH INSTITUTE

MAURITIUS SUGAR INDUSTRY RESEARCH INSTITUTE. 1991. *Mauritius Sugar Industry Resaerch Institue, Annual Report* 1990, pp 44-45.

PARISH D and FEILLAFÉ SM. 1965. *Notes on the 1:100 000 Soil Map of Mauritius*. MSIRI Occasional Paper 22, 43 pp.

SOANE BD, BLACKWELL PS, DICKSON JW and PAINTER DJ. 1981. Compaction by agricultural vehicles: A review. I. Soil and wheel characteristics. *Soil and Tillage Research* (1) : 207 - 237.

SWINFORD JM and BOEVEY TCM. 1984. The effects of soil compaction due to infield transport on ratoon cane yields and soil physical properties. *Proc. S. Afr. Sug. Tech. Ass*. : 198 - 203.

TORRES JS, YANG SJ and VILLEGAS F. 1990. Soil compaction and cane stool damage by semi-mechanized harvesting systems in the wet season. *Sugar cane* (5): 12 - 16.

ROCK PHOSPHATE AS AN ALTERNATIVE TO SOLUBLE PHOSPHATIC FERTILISERS IN ACID SOILS : 1. THE EFFECT OF PH ON THE DISSOLUTION OF ROCK PHOSPHATE

B Lalljee

University of Mauritius

ABSTRACT

Rock phosphate added to different acid soils of Mauritius responded differently with respect to percentage solubilisation. More acid soils produced a higher percentage solubilisation but did not increase proportionately with increased levels of rock phosphate added. When pH of the soils was amended the percentage solubilisation of rock phosphate was observed to increase or decrease in a negatively correlated manner. Similar trends were observed for calcium indicating that the changes in available phosphorus observed were due to the solubilisation of rock phosphate. However, the difference soils were found to behave differently in as far as the percentage increase or decrease of the rock phosphate solubilisation was concerned. The regression lines for the variations of percentage solubilisation or change in available phosphorus with respect to pH may be used to predict responses of rock phosphate in the same soil.

Keywords : Rock phosphate, percentage solubilisation, available phosphorus, acid soils, calcium, pH.

INTRODUCTION

Phosphorus fertilisation is a problem in acid soils due to the high fixation characteristics of these soils. Soluble phosphorus carriers such as triple super phosphate tend to get reverted into insoluble and slowly soluble forms, for e.g. iron and aluminium phosphates. Some soils in Mauritius have been shown to fix up to 90% of applied phosphorus (Lalljee and Coonjan 1987). The fixation characteristics as related to soil properties have been studied for some soils of Mauritius (Lalljee 1997).

Rock phosphate offers a good alternative or complement to triple super phosphate. In volcanic soils of Chile it is recommended to apply rock phosphate in combination with triple super phosphate because of the high phosphorus-retention capacity of these soils (Pino and Cassas, 1990). However, in Western Australia it has been shown that rock phosphate response is low (Bollard and Gilkes 1990). Possible explanations are slow dissolution of rock phosphate due to the moderately acid pH (5.5 –6.5), low pH-buffering capacity, low calcium absorption in soil, which increases concentration of calcium in soil solution, and poor water holding capacity of these soils.

The response of crops to rock phosphate depends not only on the solubility of rock phosphate but also on the type of soil. Gillepsie and Pope (1990) showed that in Argiaquoll, increase in rock phosphate solubility promoted plant uptake whereas in Hapludult, increased solubility resulted in less plant uptake, probably due to increased fixation in the acid, highly weathered soil. Rock phosphate solubilisation is also mediated by microorganisms. Halder et al (1990) showed that nearly all strains of *Rhizobium* and *Brady Rhizobium* solubilised rock phosphate; maximum solubilisation was achieved 3 days after inoculation. Lalljee and Facknath (1999) have shown the presence and evaluated the activities of the solubilising organisms in soils of Mauritius in a recent study.

This paper deals with the solubilisation of rock phosphate in different acid soils of Mauritius and demonstrates the effect of changing pH on this process.

MATERIALS AND METHODS

Top soils (0-20 cm) from around Cluny, Curepipe, La Pipe, Midlands and Wooton under sugarcane cultivation were collected. They were all from the high rainfall, super humid zone of the island and were acid soils. In the FAO system, they are classified as Oxisols and in the USDA system as Nitosols. The soils were air-dried, crushed to pass a 1mm sieve, and subjected to the following analyses as per established procedures outlined in Jackson (1970) : pH (1 : 2.5, soil : water) organic matter CEC Olsen's Phosphorus .

Rock phosphate was obtained from the Mauritius Chemical Fertiliser Industry and was analysed for total iron, potassium, calcium and phosphorus. 200 g of each soil sample was incubated for 14 days with various amounts of rock phosphate, giving 500 ppm, 1000ppm, 1500ppm, 2000ppm and 2500ppm phosphorus at field capacity moisture and room temperature. All samples were replicated thrice in plastic bottles. Blank samples without rock phosphate were also similarly incubated. A few drops of toluene were added in each bottle to prevent fungal growth. At the end of the incubation period, the soil samples were analysed for Olsen's Phosphorus (0.5 M $NaHCO_3$ at pH 8.5) and calcium (1 g soil extracted with 10 ml of buffered Barium chloride-Triethanolamine solution, $BaCl_2$-TEA at pH 8.5) (Hughes and Gilkes 1984).

In separate experiments the pH of the soils was amended by addition of various amounts of HCl and strontium carbonate ($SrCO_3$) and incubated for 7 days. 2000 ppm phosphorus as rock phosphate was added to each of the amended soils in triplicates and incubated as before for 14 days. Available phosphorus and calcium were extracted as above. Phosphorus was determined colorimetrically by the ammonium molybdate blue colour method, and calcium was estimated by atomic absorption spectroscopy (AAS).

Change in available phosphorus (Average P) was calculated as

Change in Average P = Average P in rock phosphate-treated soil after incubation – Average P in blank soil after incubation.

Change in Calcium = calcium in rock phosphate-treated soil after incubation – calcium in blank soil after incubation.

RESULTS AND DISCUSSION

The results of the analyses of the various soils are given in **Table 1.**

Table 1 Soil analytical results

Soil	PH	Organic matter *%*	CEC	Average P *ppm*
Cluny	5.1	5.2	8	9
Curepipe	4.6	7.6	14	10
La Pipe	4.9	4.6	10	12
Midlands	4.0	6.9	10	7
Wooton	3.9	8.7	12	8

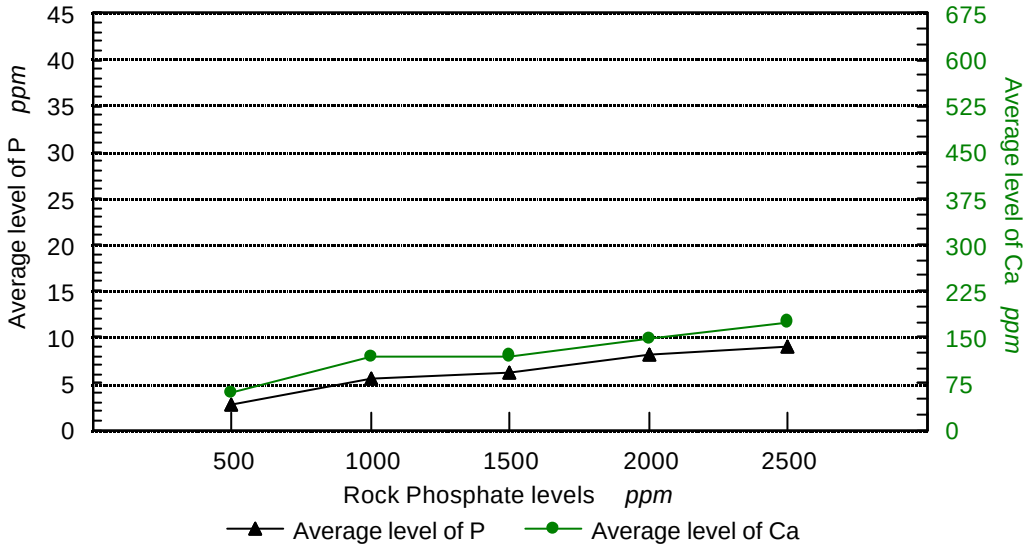
As can be seen from **Table 1** all the soils were acidic, with Wooton and Midlands being very acidic. They were medium in organic matter but had low CEC. The value of Olsen's Average P indicated that these soils would respond to phosphatic fertilisers. **Table 2** gives the composition of rock phosphate.

Table 2 Chemical composition of rock phosphate

Element	Fe	K	Ca	P
Composition %	0.52	0.18	39.95	16.53

The ratio of phosphorus to calcium was 41:100. The dissolution of rock phosphate in the different soils is shown in **Figure. 1.** The change in available phosphorus content in all the soils increased with addition of rock phosphate. However, the response in the different soils varied, being greater in Wooton soil as compared to Cluny. Maximum percentage dissolution of rock phosphate occurred in Wooton soils at all the rock phosphate levels, being 4.40%, 2.95%, 1.77%, 1.41% and 1.21% at the different treatments respectively.

Figure 1 Average levels of P and Ca with addition of rock phosphate in Cluny soil



Maximum change in Average P (30.2 ppm phosphorus) was observed for Wooton soils at the 2500 ppm phosphorus treatment, and minimum change in Average P was observed for Cluny soils (2.7 ppm phosphorus) at the 500 ppm phosphorus treatment. Although there was an increase in Average P in the soil as the rate of application of rock phosphate increased from 500 to 2500 ppm, the rate of dissolution of rock phosphate in fact decreased from 4.04% to 1.21% in Wooton soils. Similar trends followed for the other soils (**Figures 2-5**). The values of rock phosphate solubilisation might not express the true picture as the solubilised phosphorus might immediately be converted into other less soluble forms, e.g. $Al(OH)_2PO_4$, $Al(PO_4)_3$ etc. In fact, decrease in solubility of rock phosphate with time has been reported by several workers (Smith and Sanchez 1987) in Cerrado soils in Brazil.

Figure 1 also gives the changes in soil calcium, and it is interesting to note that it follows the same trend as changes in Average P for all the soils, indicating that the changes in the Av soil phosphorus reflects phosphorus coming from solubilisation of rock phosphate.

Figure 2 shows changes in Average P with changes in pH of soil for Cluny soil. As the pH increases, the change in Average P decreases and vice versa. The corresponding changes in calcium support the fact that the increase in soil phosphorus recorded is due to the dissolution of the added rock phosphate

Similar trends were observed for the other soils, as shown in **Figures 6-10**. They all showed a linear decreasing trend of change in Average P. This also implies a lower dissolution rate of rock phosphate with increasing pH. The percentage dissolution at the various pH levels for the different soils are shown in **Table 3**.

Figure 2 Average levels of P and Ca with addition of rock phosphate in Curepipe soil

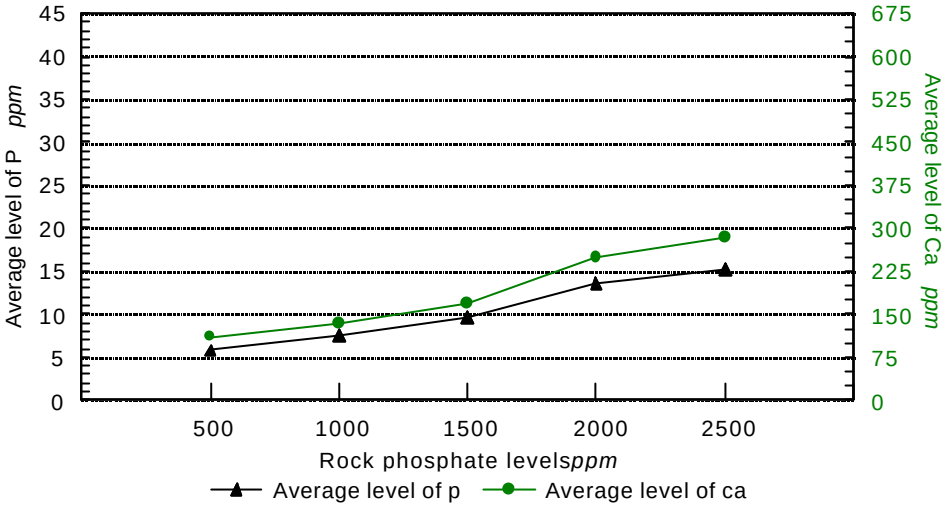


Figure 3 Average levels of P and Ca with addition of rock phosphate in La pipe soil

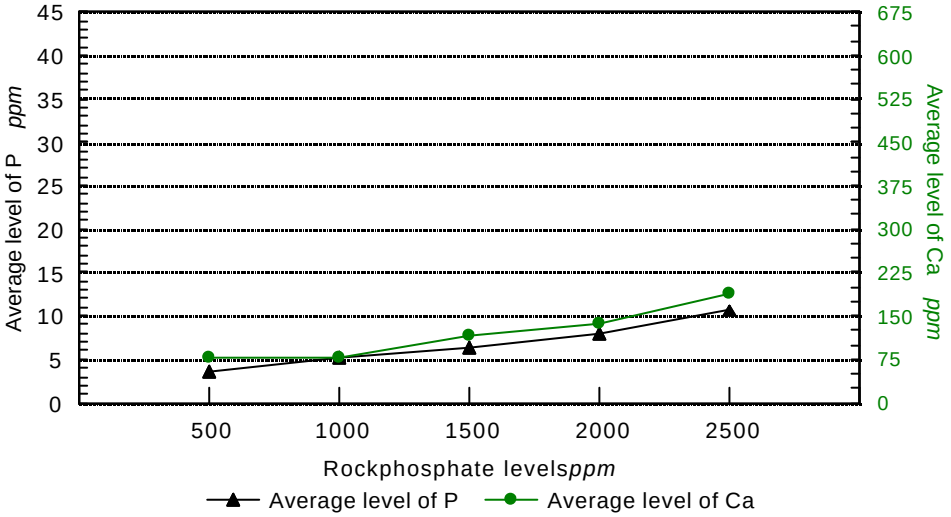


Figure 4 Average levels of P and Ca with addition of rock phosphate in Midlands soil

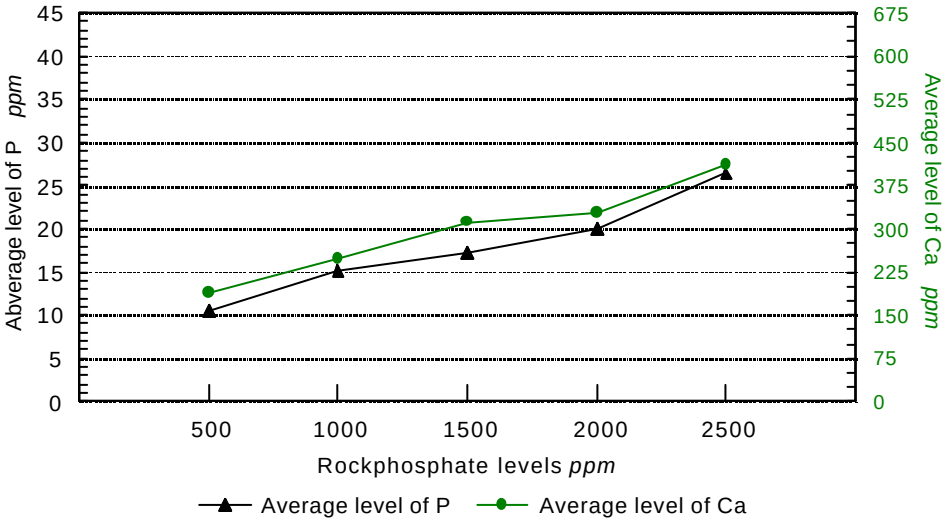


Figure 5 Average levels of P and Ca with addition of rock phosphate in Wooton soil

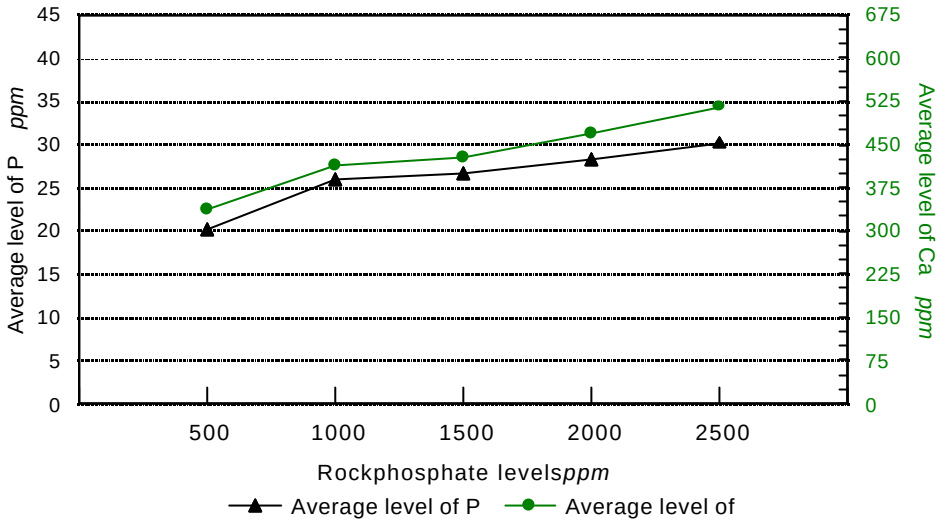


Figure 6 Average Levels of P and Ca at different pH levels in Cluny soil

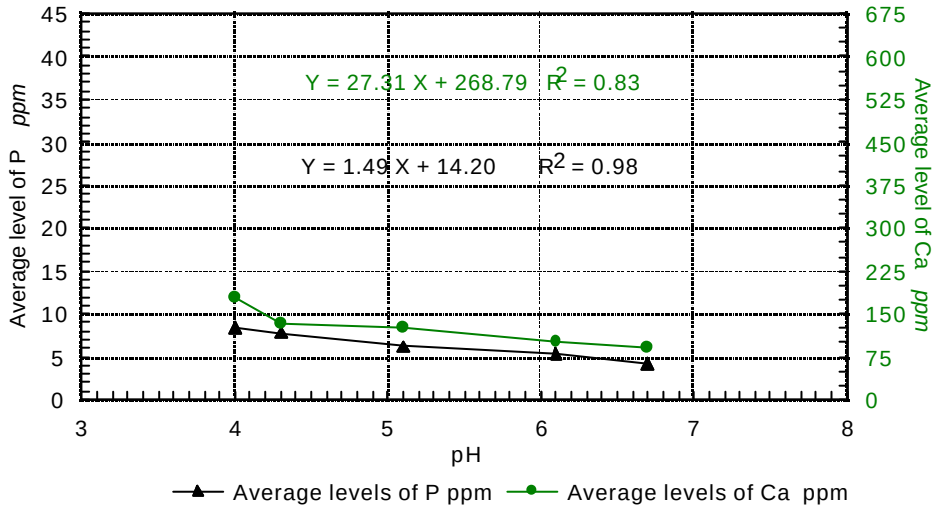


Figure 7 Average Levels of P and Ca at different pH levels in Curepipe soil

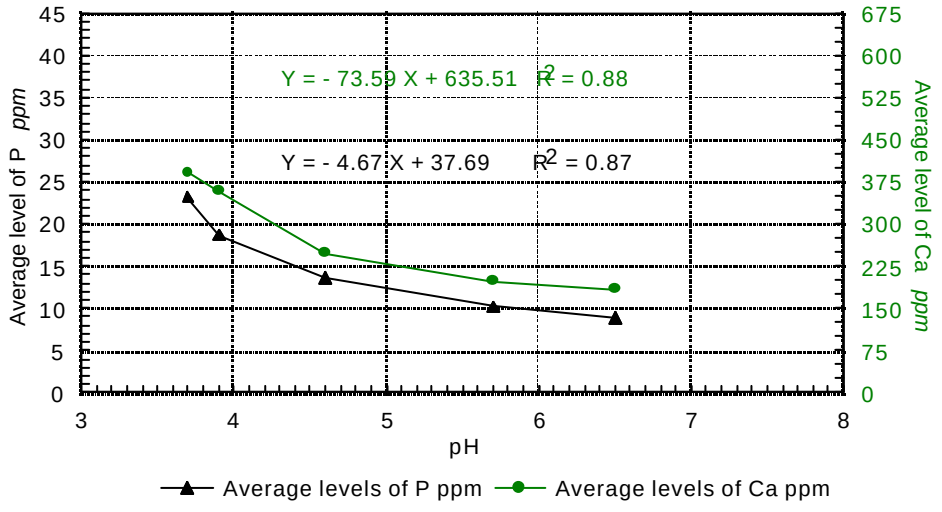


Figure 8 Average Levels of P and Ca at different pH levels in La pipe soil

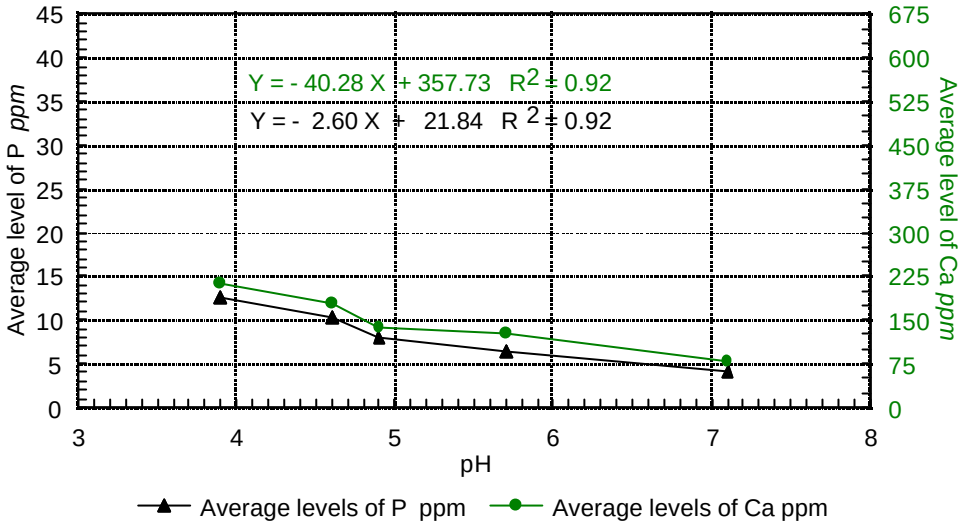


Figure 9 Average Levels of P and Ca at different pH levels in Midlands soil

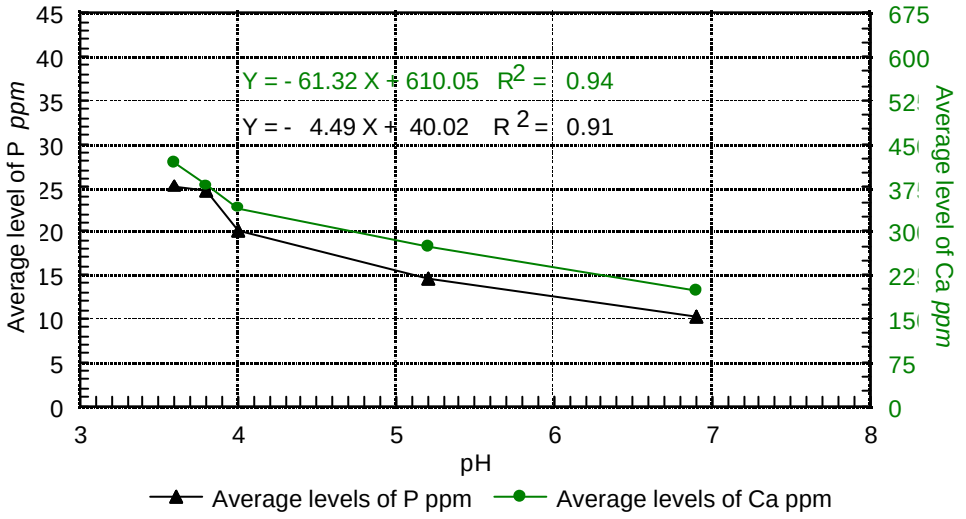


Figure 10 Average Levels of P and Ca at different pH levels in Wooton soil

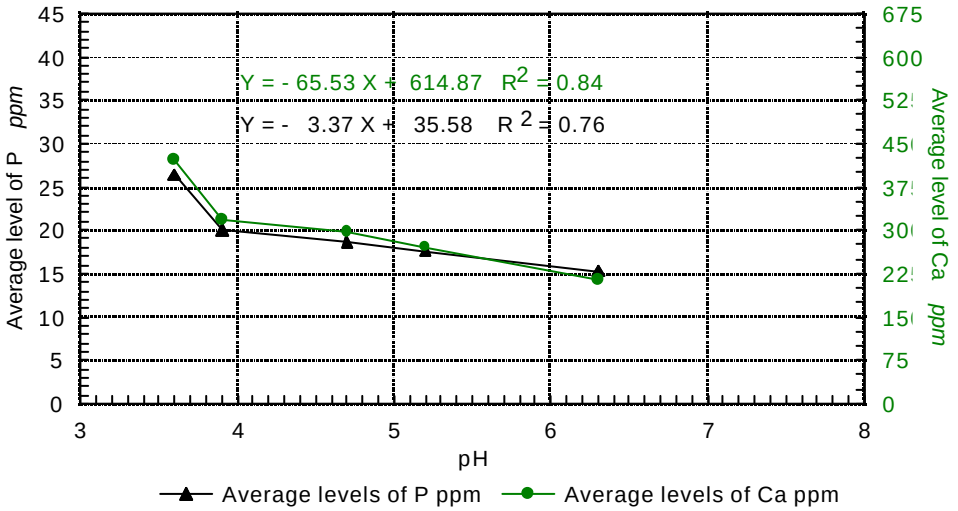


Table 3 Percentage dissolution of rock phosphate with varying soil pH

Cluny	pH	4.0	4.3	5.1	6.1	6.7
	Dissolution (%)	0.42	0.39	0.31	0.27	0.21
Wooton	pH	3.6	3.9	4.7	5.2	6.3
	Dissolution (%)	1.32	1.00	0.91	0.88	0.77
Curepipe	pH	3.7	3.9	4.6	5.7	6.5
	Dissolution (%)	1.16	0.94	0.68	0.51	0.45
La Pipe	pH	3.9	4.6	4.9	5.7	7.1
	Dissolution (%)	0.63	0.51	0.40	0.32	0.21
Midlands	pH	3.6	3.8	4.0	5.2	6.9
	Dissolution (%)	1.26	1.23	1.00	0.73	0.51

As can be seen from **Table 3** the percentage dissolution changes not only with change in pH, but also depends upon the nature of the soil. When we consider only one soil, i.e. all other soil properties are kept constant; the decrease in percentage solubilisation of rock phosphate caused by an increase in pH indicates a supply of hydrogen ions. This supply of hydrogen ions from the soil depends upon the buffering capacity of the soil. Soils having a large amount of reserve acidity therefore can provide more of hydrogen ions than those soils having low reserve acidity. This could be one of the reasons for the difference in the percentage dissolution observed in the various soils. In fact rock phosphate dissolution has been shown to be linearly correlated with titratable acidity (which is a measure of reserve acidity) of some soils in Australia (Kanabo and Gilkes 1987). The equation describing the increased solubility with decreased pH can be put in the form:

$$Ca_{10}(PO_4)_6(OH)_2 + 20\,H^+ \rightarrow 10\,Ca^{++} + 6H_3PO_4 + 21H_20$$

Although the equation relates to a hydroxy-apatite it would be similar for other rock phosphate in the apatite group.

CONCLUSION

The study shows that in the acid soils of Mauritius rock phosphate may be used to increase available phosphorus. However, the concentration of available phosphorus from the same type and amount of rock phosphate will depend on the soil. For a specific soil the amount of available phosphorus obtainable from rock phosphate is dependent upon the pH of the soil, keeping all other factors, such as incubation or time of application constant. The lower the pH, the higher is the percentage solubilisation of rock phosphate. The study also shows that increasing application of rock phosphate does not always bring about a corresponding increase in available phosphorus in the soil. The regression equations accompanying the graphs may be used to predict rock phosphate response in the same soil but differing in pH.

REFERENCES

BOLLARD M and GILKES RJ. 1990. The poor performance of rock phosphate fertilisers in Western Australia. Part I. The crop and pasture response. *Agricultural Sc.* 3(1). 43-48.

GILLEPSIE AR and POPE PE. 1990. A comparison of three rock phosphates for use in forest soils. *Fertiliser Res*. 23(3). 141-145.

HALDER AK, MISHRA AK, BATTACHARYA P and CHAKRABORTHY PK. 1990. Solubilistiaon of rock phosphate by *Rhizobium* and *Brady Rhizobium. J. Gen. and Appl. Microbiol*. 36(2). 81-92.

HUGHES JC and GILKES RJ. 1984. Effect of chemical extractants on the estimation of rock phosphate fertiliser dissolution. *Aust. J. Soil Res*. 22. 484-487.

JACKSON ML. 1970. *Soil Chemical Analyses*. Prentice Hall, India.

KANABO IA and GILKES RJ. 1987. The role of soil pH in the dissolution of phosphatic rock fertilisers. *Fertiliser Research* 12. 165-174.

LALLJEE B and COONJAN N. 1987. Soils. *Annual Report of the Agricultural Servic*es, Ministry of Agriculture, Fisheries and Natural Resources, Mauritius, 1984, 113-115.

LALLJEE B and FACKNATH S. 1999. Organisms solubilising phosphorus in soils of Mauritius. *African Soils/Sols Africain*. [*In Press*].

LALLJEE B. 1998. Phosphorus fixation as influenced by soil characteristics of some Mauritian soils. *In* Lalouette JA et al. Eds. *Proceedings of the 2nd Annual Meeting of Agricultural Scientists*, August, 1997, Mauritius. pp 115-121.

PINO I and CASSAS L. 1990. Phosphatic rock appraisal in volcanic ash soils of Chile. *In* : Transactions 14th Int. Cong. Soil Sc. Kyoto, Japan, IV. 122-125.

SMITH TJ and SANCHEZ PA. 1982. Phosphate rock dissolution and availability in Corrado soils as affected by phosphorus sorption capacity. *Soil Sc. Soc. Amer. J.* 47. 339-345.

STATUS OF PINK ROOT ROT IN ONION AND ITS CONTROL IN MAURITIUS

F Maudarbaccus **and** *SP Beni Madhu*

Agricultural Research and Extension Unit

ABSTRACT

Surveys carried out in 1998 in 30 fields at La Marie and 107 fields at Belle Mare have confirmed the prevalence of the Pink Root Rot disease in these traditional onion-growing areas. In preliminary on-farm trials on naturally infected soil at La Chaumière, soil fumigant dazomet applied at 70 g m^{-2} reduced pink root rot expression appreciably and increased fresh bulb yields substantially.

Key words: Onions, *Pyrenochaeta terrestris*, pink rot, control,soil fumigants.

INTRODUCTION

The bulk of onion produced commercially in Mauritius traditionally comes from three zones comprising Belle Mare, Palmar, Trou-d'Eau-Douce, Petit Sable and Grand Sable in the East of the island, La Marie in the Centre and La Chaumière in the West. Repeated cropping of onion on the same land in these regions has produced a downside by way of increased disease pressure due to soil-borne plant pathogens, particularly the pink root rot (PRR) disease caused by the fungus *Pyrenochaeta (Phoma) terrestris* (Hansen et al. 1949) The first record of widespread occurrence of the disease on onion in Mauritius dates back to 1967 (Anon 1967). The disease is a worldwide constraint to onion production of (Pages and Notteghem 1996). and is known to attack the root system causing pink discoloration, root rot and collapse resulting in reduced yield.

In 1995, attention of the Mauritian authorities was drawn to the fact that onion crops at La Chaumière, La Marie and Belle Mare were affected by the PRR disease and the situation warranted investigation (Grobler 1995). A field survey carried out at La Chaumière in August 1996 as a follow up revealed a high incidence of the PRR disease at varying intensity and distribution in approximately 16 ha that had been cropped with onion since the seventies. The exercise was repeated at Belle Mare and La Marie in 1998 with the aim of assessing the importance of the disease in these regions, and to eventually devise management / control strategies.

This paper describes surveys carried out to assess the distribution and incidence of the disease at Belle Mare and La Marie and also reports on preliminary on-farm trials undertaken with soil fumigant dazomet for its control at La Chaumière.

MATERIALS AND METHODS

Details on the survey sites and sampling are presented in **Table** 1. They relate to:

Survey sites

Belle Mare

The Belle Mare area, with a total acreage of 77.4 hectares devoted to onion cultivation, is divided into five blocks as follows: Block I (Flacq) of 12.28 hectares, Block II (Ajanta) of 33.21 hectares, Block III (Quatre Cocos) of 11.34 hectares, Block IV (Palmar Campements) of 12.41 hectares and Block V

(Palmar Land Settlement) of 8.16 hectares. The soil belongs to the Latosolic Reddish Prairie type and visibly changes to the dark brown soil of the Regosols towards the coast. Land is flat or almost flat to gently undulating and sloping. Fields were irrigated by overhead sprinklers and the onion varieties, which predominated, were Local Red and Véronique.

The sampling area surveyed from September 22 through October 14, 1998 covered 15.2 ha representing 20 % of the total area planted with onion. In all, 107 fields were surveyed and 1605 samples collected.

La Marie

The area surveyed over the period November 9 to 22, 1998 at La Marie totalled 18 ha representing 15 % of the total area of 122 ha under onion in that region. The soil belongs to the Latosolic Brown Forest type on land almost flat to sloping and undulating. Fields were mostly rain fed and were irrigated with overhead sprinkler irrigation whenever necessary. The varieties of onion found predominating were Yellow Dessex, Sivan and Savannah Sweet. Thirty fields were surveyed and 450 samples collected.

Table 1 Profile of survey sites on onion at Belle Mare and La Marie, 1998.

Date	Site	Total area *Ha*	Area surveyed *ha*	Samplng area *%*	Fields surveyed *No*	Varieties grown	Samples collected *No*	Sampling stages *weeks after transplanting*
Sep 22 to Oct 14	Belle Mare	77.4	15.2	20	107	Local Red Véronique	1605	9-12
Nov 9 to 23	La Marie	122	18	15	30	Sivan Yellow Dessex Savannah Sweet	450	9-12 weeks after transplanting

Survey Methodology

At both sites i.e. Belle Mare and La Marie, sampling was done 9 to 12 weeks after transplantation. In each field surveyed, fifteen plants were randomly uprooted with care by means of a dibble so as to minimise damage to the root system. They were labelled and taken to the laboratory for analysis. The root system of each plant was carefully washed in slow running water and inspected for any typical pink discoloration, characteristic of PRR infection. A plant with at least one root showing pink discoloration was considered as infected. The number of infected roots and the total number of roots of each plant sampled were noted and the percentage root infection calculated to indicate field infection levels.

Soil treatment trials with dazomet

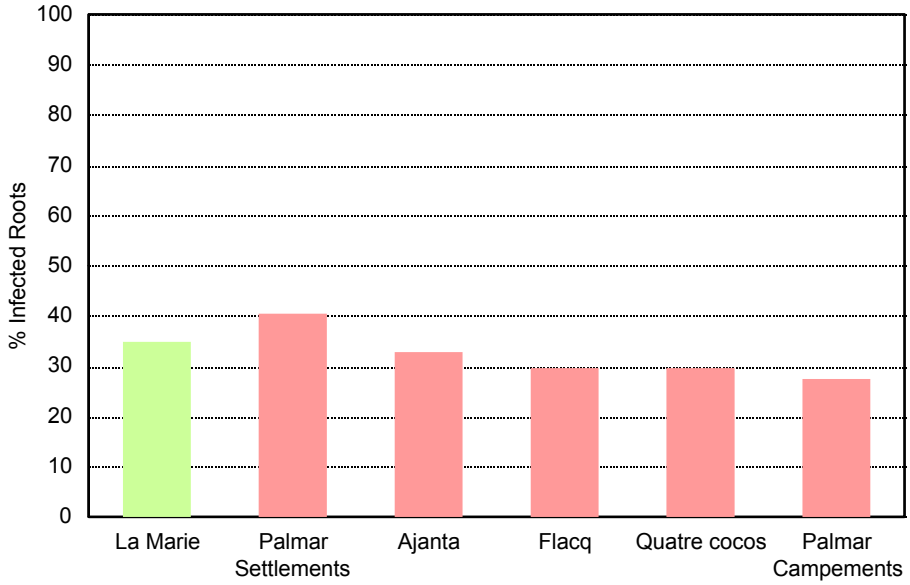
Two preliminary on-farm trials consisting of soil fumigation with dazomet were conducted concurrently at La Chaumière in April 1998 in two specific locations known to be naturally and highly infected with the PRR pathogen. For both trials, two beds measuring 6 m^2 each were prepared as per standard practices. One of the beds was treated with dazomet at the rate of 70 g m^{-2} in the first week of April while the second bed was left untreated. Three weeks after, seeds of Yellow Dessex variety were sown on the beds. Two plots of 12 m^2 each were prepared for transplantation at the beginning of June. Seedlings from treated beds were transplanted to the treated plots three weeks later. At the same time seedlings from untreated beds were transplanted to untreated plots. Cultural practices followed were in line with recommendations for growing onion as contained in the Guide Agricole 98- Cultures Légumières (1998). The development of the plants was closely monitored over the whole cycle. Disease assessment was done as described earlier under section B on 'Survey Methodology'. However in this case, thirty plants were randomly uprooted with care per treatment at three distinct stages viz. bulb initiation, bulb development and bulb maturation at 8, 10 and 12 weeks after transplantation respectively. Records were also kept of bulb diameters and weights.

RESULTS AND DISCUSSION

Survey findings

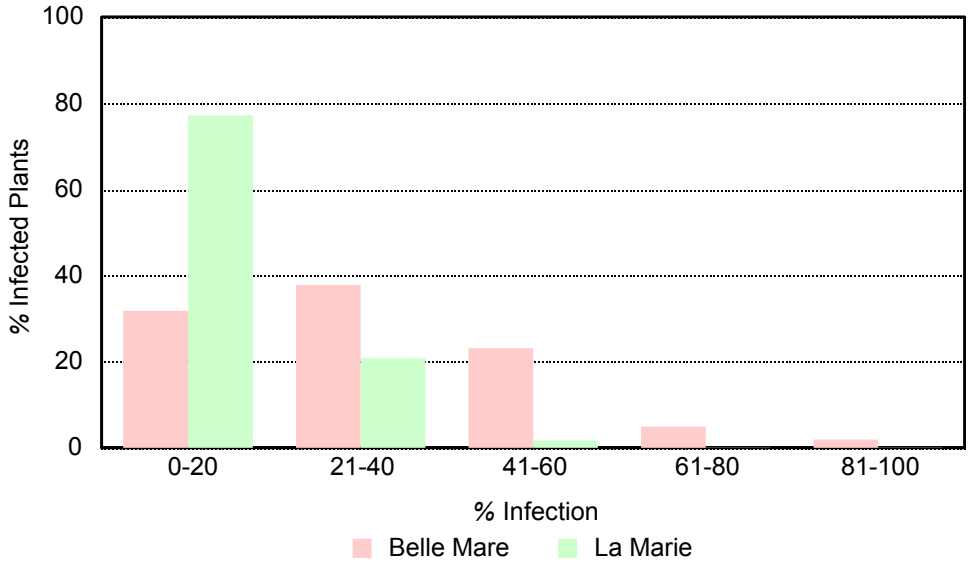
The incidence of PRR disease in the regions of Belle Mare and La Marie is shown in **Figure 1.** Assuming that the percentage of infected roots gives an indication about the inoculum level in the soil, it can be concluded that the regions planted to onion in Belle Mare and at La Marie are infected with the PRR pathogen to more or less the same extent, in the range of 35 % ± 7 %.

Figure 1 Incidence of PRR disease in Belle Mare and La Marie, 1998



It may be inferred also that the fungus adapts to both sandy and clayish soils as found at Belle Mare and La Marie respectively and could thus spread across the country if new areas were opened up to the crop. From **Figure2**, which shows the distribution of infection in plants, it is evident that a higher number of plants from Belle Mare tended to fall in higher infection ranges than those from La Marie.

Figure 2 Distribution of PRR infection at La Marie and Belle mare1998



Indeed two out of every three plants at Belle Mare fell in an infection range exceeding 20 %, whereas at La Marie only one plant out of four was in that infection range. This could be explained by the fact that varieties grown (Sivan, Savannah Sweet, Yellow Dessex) at La Marie are reckoned as PRR resistant in contrast to the varieties Véronique and Local Red planted at Belle Mare. Another possible explanation is the occurrence of the root knot nematode (*Meloidogyne sp.)* at Belle Mare (Lambertii et al. 1985) and possible interaction with the fungal pathogen *Pyrenochaeta terrestris* (Pitcher 1963).

Soil fumigation trials with dazomet.

The effects of dazomet were evaluated at harvest, with all sampled bulbs checked for disease expression, diameter and weight, the results of which are shown in **Table 2**.

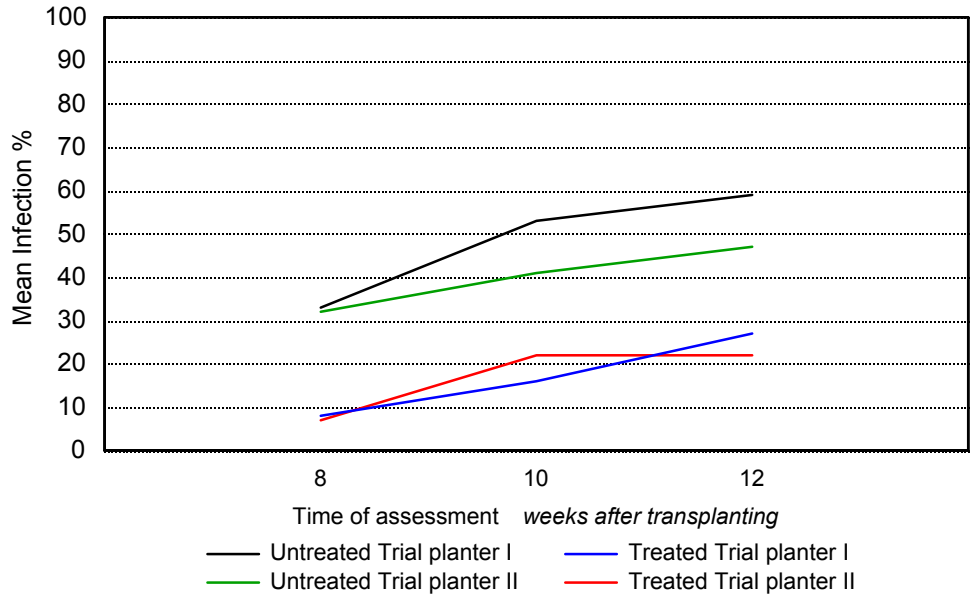
Table 2 Effects of dazomet on PRR expression, bulb diameter and fresh yields of onion at La Chaumière, 1998.

Trial	Dazomet treated plot Averages			Untreated plot Averages			Increase	
	Infection *%*	Bulb ∅ *mm*	Yield *t-ha^{-1}*	Infection *%*	Bulb ∅ *mm*	Yield *ha^{-1}*	Bulb ∅ *%*	yield *%*
Planter I	27	53.0	48.4	59	41.1	30.8	29	57
Planterl II	22	50.8	48.4	47	47.1	35.2	8	37

Infection dynamics

The kinetics of infection in both trials conducted concurrently at La Chaumière are presented in **Figure 3** to indicate disease development at 8, 10 and 12 weeks after transplantation in both treated and untreated plots.

Figure 3 Kinetics of PRR infection in onion, 1998

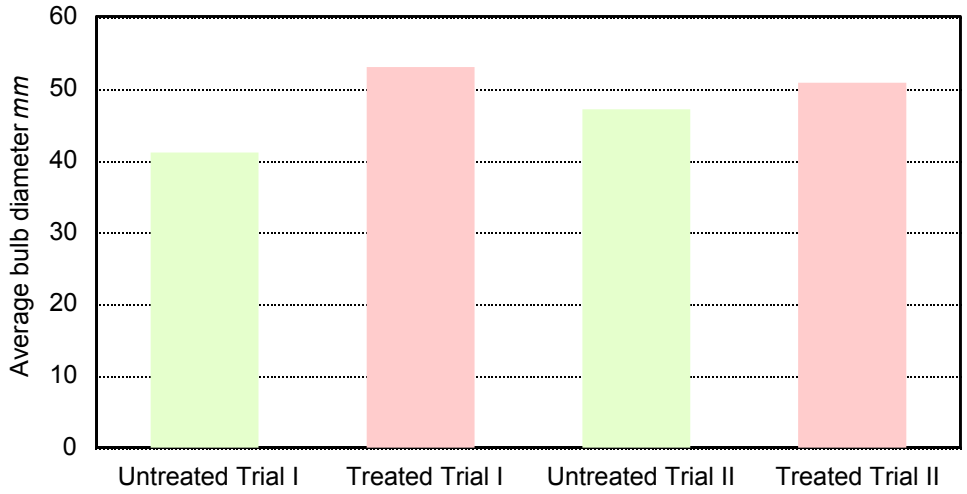


A significant reduction ranging between 19 to 37 % in pink root rot expression was obtained with the application of the soil fumigant dazomet. Actually infection in treated soil peaked at around 20 % 10 weeks after transplanting and showed a tendency to level off thereafter. In untreated soil by contrast, it was observed that infection increased continuously throughout the period of assessment i.e. from bulb initiation right to the harvesting stage.

Bulb diameter at harvest

The average bulb diameter at harvest and the fresh yields obtained in both trials are given in **Figures 4** and **5** respectively.

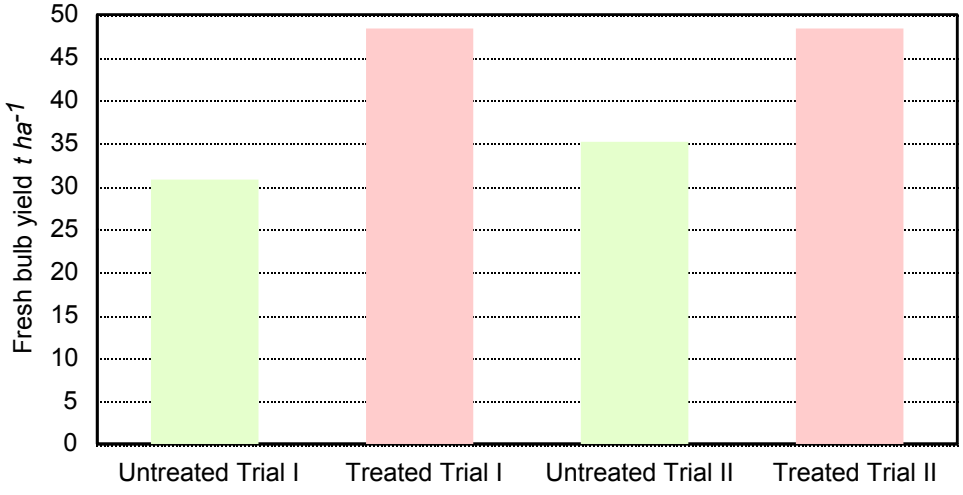
Figure 4 Bulb diameter at harvest



Differences in bulb size were prominent as plants in treated plots produced on average bulbs of larger diameter with the increase lying between 8 % in Trial II to 29 % in Trial I. As expected, these differences were reflected in crop yields, in conformity with the findings of (Pages and Notteghem 1996).

Yield of fresh bulbs

Figure 5 Yield of fresh bulbs, La Chaumière, 1998



Total fresh bulb yields were in fact higher in dazomet-treated plots, with production gains of 57 % in Trial I and 37 % in Trial II.

CONCLUSION

This study has confirmed the prevalence of pink root disease on onion at Belle Mare and La Marie. It also revealed that both regions are infected to nearly the same extent. Preliminary on–farm investigations at La Chaumière have shown that soil fumigation could confer some measure of control over the disease. The use of fumigant dazomet was found to reduce infection and increase yields of fresh onions markedly to 57 %. However the observed efficacy of dazomet needs to be confirmed through further experimentation.

ACKNOWLEDGEMENT

The authors express their sincere thanks to Mr. S.N. Naidu, Director AREU, Mr. D Dumur, Assistant Director (Crops) AREU, Mr. R. Ramnauth, Biometrician, AREU, for their help and encouragement in the preparation of this paper.

REFERENCES

AGRICULTURAL RESEARCH and EXTENSION UNIT. *Guide Agricole 98-Cultures Légumières* 1998. Réduit, Mauritius, Agricultural Research and Extension Unit.

ANON. 1967. *Annual Report Ministry of Agriculture, Fisheries and the Natural Resources*, p.77

AREU *see under* Agricultural Research and Extension Unit.

GROBLER 1995. Internal Report, Onion Producers Association (OPA).

HANSEN HN, GORENZ AM, LARSON RH and WALKER JC. 1949. Factors affecting pathogenicity in pink root fungus of onions. *J .Agr. Res*. 78: 1-18.

LAMBERTII F, DI VITO M, SCRANO L, CHINAPPEN M and BUCHA J. 1987. Root-knot nematodes, Meloidogyne species, in Mauritius and Rodrigues. *FAO, Plant Protection Bulletin* vol. 35, No 2, pp 43 -49.

PAGES J and NOTTEGHEM JL. 1996. Effects of soil treatment practices on pink root disease of onion in the Senegalese cultivation system. *International journal of pest management*. 42 (1) 29-34.

PITCHER RS. 1963. Interrelationships of nematodes and other pathogens of plants. *Helminthological Abst*. 34: 1-17.

EVALUATION OF FUNGICIDES FOR CONTROL OF THE LEAF SPOT DISEASE CAUSED BY *Mycosphaerella eumusae* ON BANANA IN MAURITIUS

SD Soomary* and *SP Beni Madhu

Agricultural Research and Extension Unit

ABSTRACT

A leaf spot disease caused by newly described fungal pathogen Mycosphaerella eumusae is one of the most important constraints of banana cultivation in Mauritius. Field trials conducted for evaluation of fungicides for its control in 1997 and 1998 on banana revealed the efficacy of tebuconazole (Folicur), particularly in combination with the emulsifiable petroleum adjuvant Bacoil.

Keywords : Bananas,*Musa* spp.,disease, *Mycosphaerella eumusae,* leaf spot,control, fungicides,Bacoil, adjuvant..

INTRODUCTION

A leaf spot disease of banana was reported for the first time in Mauritius in 1995. Its symptoms, development and its management based on existing recommended cultural practices have been described by Soomary and Beni Madhu (1998). Diagnosis work performed on the fungal pathogen since its occurrence consistently revealed the involvement of an undescribed *Mycosphaerella sp*. In 1998, the pathogen was identified as belonging to a new species and was named *Mycosphaerella eumusae* by Mourichon working at CIRAD-FLHOR in Montpellier, France (Pers comm., 1998). Field trials were undertaken in parallel with the taxonomical studies to evaluate fungicides for control of the disease. This paper outlines findings of these preliminary fungicide trials conducted on farm in 1997 and 1998.

MATERIALS AND METHODS

Field trials were laid out in existing orchards on the premises of Le Val Nature Park in 1997 and at Médine Sugar Estate, Bambous, and the year after. Le Val Nature park is situated in the super humid zone, with an average annual rainfall of 2500 mm., while Medine S.E is found in the subhumid western part of the island, with an average of 500 mm. The plantation at Le Val was thus rain fed whereas, at Médine S.E, overhead irrigation was practised. Standard orchard management practices were otherwise similar at both sites.

At le Val, the observational fungicide trial was conducted on cultivar Williams, and consisted of the following eight treatments:

T1: Folicur (tebuconazole) @ 0.4 ml l^{-1}
T2: Benlate (benomyl) @ 0.5 g l^{-1}
T3: Topsin (thiophanate methyl) @ 2 ml l^{-1}
T4: Score (difeconazole) @ 0.5 ml l^{-1}
T5: Folicur/Topsin in alternation at above rates
T6: Folicur/Benlate in alternation at above rates.
T7: Folicur/Score in alternation at above rates.
T8: Control (unsprayed).

Complement, a medium range mineral oil, was incorporated in the spray mixture @ 1 ml l^{-1} for all treatments. The spray mixture was stirred for 4 to 5 minutes until a stable emulsion was obtained. Ten plants in paired rows were sprayed per treatment. Experimental plots were separated by unsprayed rows to provide inoculums for test plots and to protect against drifts. Three foliar sprays were applied on 31 March, 02 May and 10 June 1997, using a motor blow.

Visual assessment, based on the Youngest Leaf spotted (YLS) were made 31 March, 25 April, 16 May, 6 and 20 June1997 using the leaf spot evaluation scale developed by Stover and Dickson (1970), where 0= clean leaf, 1= less than 5% leaf area infected, 2= from 5 to 15%, 3= from 16 to 33% and 4= more than 33%. In the trial, the youngest fully expanded leaf starting from the heart (cigar) leaf was considered as leaf number 1. The YLS was the first leaf showing at least 10 spots with a necrotic dry centre. When several lesions coalesced to form a large necrotic area, each dry centre was counted as a former single spot. The percentage of infected leaves was also recorded.

At Médine S.E , the trial was laid out with cultivar Dwarf Cavendish in a randomised block design with 4 replicates and five treatments consisting of:

T1: Folicur @ 0.4 ml l^{-1} with Bacoil
T2: Folicur @ 0.4 ml l^{-1} in alternation with Benlate @ 0.5 ml l^{-1}
T3: Folicur @ 0.4 ml l^{-1} in alternation with Topsin @ 2 ml l^{-1}
T4: Folicur @ 0.4 ml l^{-1} without Bacoil.
T5: Control (unsprayed)

Bacoil, an emulsifiable petroleum adjuvant currently used in banana producing countries for the control of the black leaf streak disease of banana, was incorporated at the rate of 35 ml l^{-1} of spray mixture for treatments T1, T2 and T3. The required volume of Bacoil was added to an equal volume of water and the resulting mixture stirred for 4 to 5 minutes until a stable emulsion was obtained. The recommended amount of fungicide was added to the mixture, which was then made up to the required volume with water.

In each experimental plot, five plants were sprayed with the oil-water-fungicide emulsions. As at Le Val trial plots were separated by unsprayed rows to provide inoculum and to protect against drifts. Three foliar sprays were applied in this case on 16 April, 15 May and 18 June 1998, using a motor blow. Disease assessment based on YLS and percentage of infected leaves were effected as for Le Val on 15 April, 29 April, 27 May, 12 June and 03 July 1998.

RESULTS AND DISCUSSION

Results for Le Val in terms of percentage of infected leaves and average YLS are presented in **Table 1** and separately in **Figures 1** and **2.**

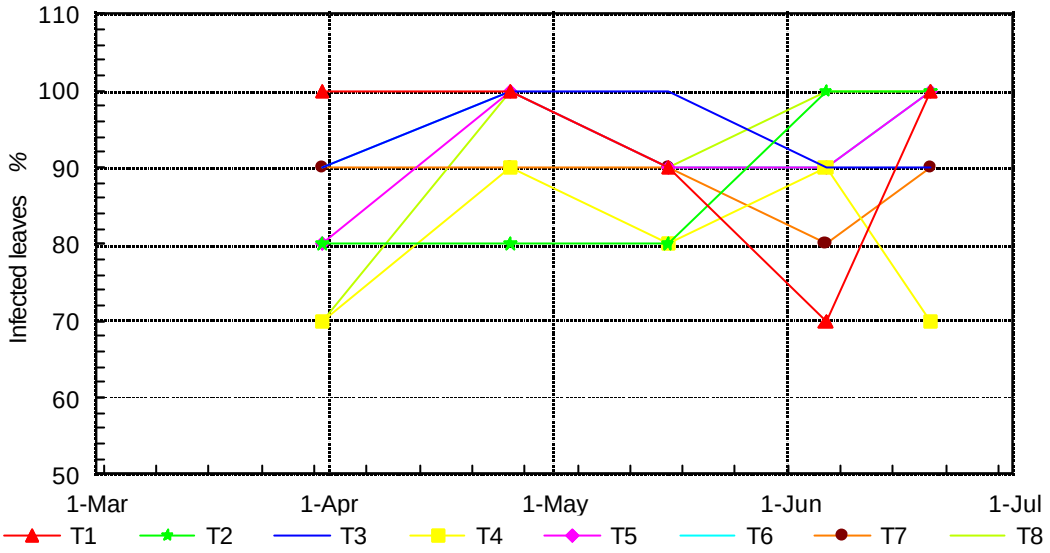
Table 1 Evaluation of fungicide treatments at Le Val, 1997.

Assment dates	T1		T2		T3		T4		T5		T6		T7		T8	
	% L.I*	Yls Av	% L.I*	Yls Av	% L.I*	Yls Av	% L.I*	Yls Av	% L.I*	Yls Av	% L.I*	Yls Av	% L.I*	Yls Av	% L.I*	Yls Av
31 Mar	100	5.9	80	6.2	90	6.3	70	6.0	80	5.4	100	5.8	90	5.8	70	5.8
25 Apr	100	6.2	80	7.0	100	6.4	90	6.2	100	5.8	100	6.5	90	6.3	100	5.8
16 May	90	6.6	80	6.9	100	6.1	80	6.4	90	6.4	90	6.8	90	6.4	90	5.7
6 Jun	70	6.6	100	5.9	90	4.6	90	6.0	90	6.0	90	6.5	80	5.6	100	5.3
20 Jun	100	6.5	100	5.7	90	4.6	70	6.1	100	5.6	100	5.7	90	5.2	100	4.3

*L.I: Percentage of leaves infected.

In the evaluation of infected leaves exercise (**Figure 1**) it is striking to note that initial infection was very high, more than 70% in all cases, even reaching 100% in two cases

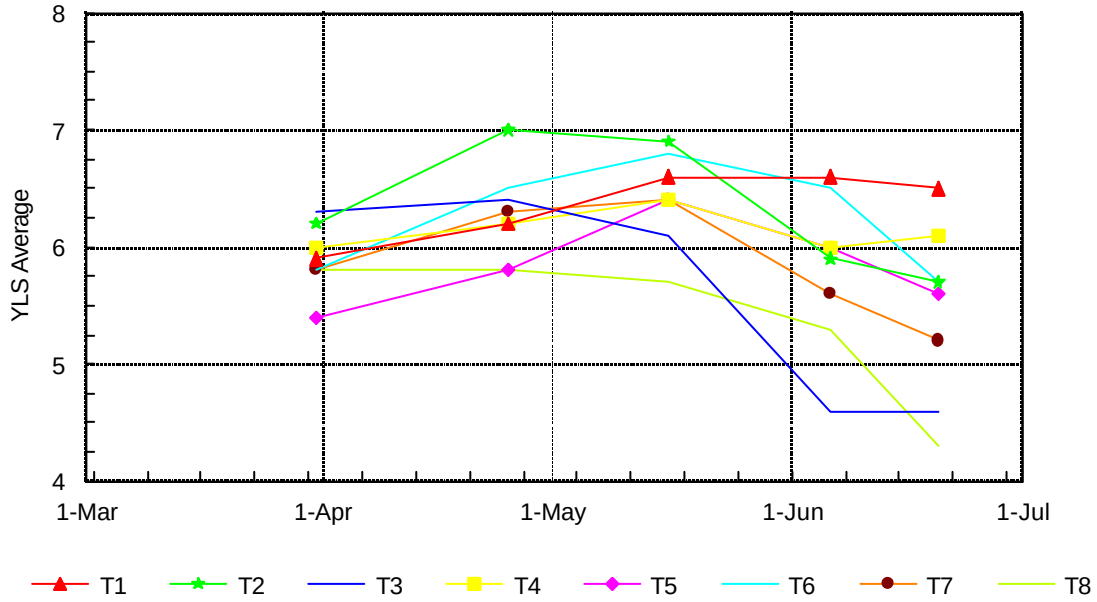
Figure 1 Disease response to fungicide treatments at Le Val, 1997



It was also observed that infection tended to fluctuate over time irrespective of treatments applied, and corroborates with findings of a study carried out in Ecuador by Bayer Agrochemicals in the control of Black Sigatoka disease of banana caused by *Mycosphaerella fijiensis* (Morelet) (Anon 1996). No definite trend was thus obtained and based on this no conclusion could be reached on the efficacy of any of the fungicides tested. They did not seem to confer any advantage over the unsprayed plot (control).

Figure 2 shows the evaluation of the Youngest Leaf spotted (YLS) in the trial. The significance of this parameter in the evaluation of the performance of fungicides lies in monitoring the progression of the disease. As disease progresses, infection tends to shift to younger leaves thereby decreasing the average YLS.

Figure 2 Evaluation - Youngest Leaf Spotted (YLS) in fungicide trial at Le Val, 1997



At Le Val , it was noted that when plants were not treated (unsprayed plot) average YLS decreased from 5.8 to 4.3, implying progression of the disease towards the heartleaf. Except for T3 (Topsin) all the other treatments achieved some degree of control with the YLS moving away from the heartleaf. Among the fungicides, Folicur stood out as the best with an average YLS of 6.5 at the end of the trial.

Results for Médine are compiled in **Table 2** , and are displayed separately for percentage of infected leaves and Youngest Leaf Spotted in **Figures 3** and **4** respectively.

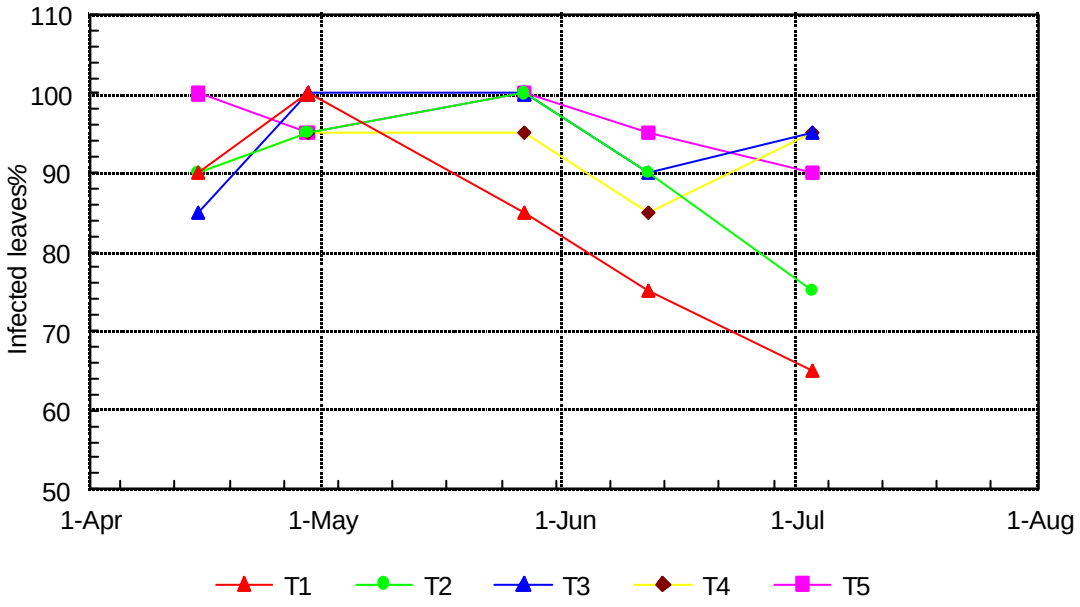
Table 2 Evaluation of fungicide treatments at Médine, 1998

Assessment dates	T1		T2		T3		T4		T5	
	% LI	Yls Av	% LI	Yls Av	% LI	Yls Av	% LI	Yls Av	% LI	Yls Av
15 Apr	90	6.5	90	7.3	85	6.9	90	7.3	100	7.1
29 Apr	100	6.3	95	6.1	100	6.6	95	6.6	95	6.3
27 May	85	6.6	100	5.8	100	6.7	95	6.1	100	5.8
12 Jun	75	7.2	90	6.5	90	7.2	85	6.1	95	6.2
3 Jul	65	7.6	75	5.9	95	6.2	95	6	90	5.3

*L.I: Percentage of leaves infected.

As for Le Val, disease response measured in terms of percentage-infected leaves (**Figure. 3**) tended to follow a similar fluctuation pattern in all but one case, in T1 (Folicur). Indeed with the application of the Folicur and Bacoil emulsion, percentage of infected leaves went down steadily from 100% to 65%.

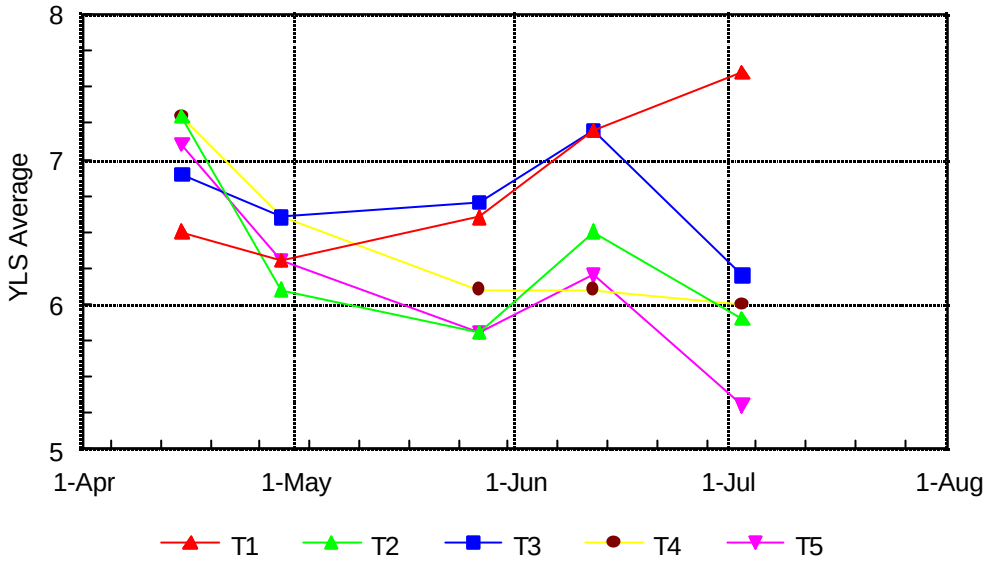
Figure 3 Disease response to fungicide treatments at Médine, 1998



The superiority of T1 (Folicur + Bacoil) was again apparent as evidenced by an increased of YLS from 6.5 to 7.6 (**Figure. 4**)

It contrasted sharply with other treatments, including T4 (Folicur alone), where the average YLS followed a downward trend. It could well indicate the advantage of incorporating Bacoil in the fungicide mixture and highlights its complementary relationship with Folicur.

Figure 4: Evaluation - Youngest Leaf Spotted (YLS) in fungicide trial at Médine, 1998



CONCLUSION

Observational trials conducted in 1997 and 1998 confirmed the prevalence of the disease caused by newly described fungal pathogen, *Mycosphaerella eumusae* at both experimental sites in two distinct agro climatic zones, namely Le Val (super humid) and Medine (sub humid). Fluctuation in the incidence of the disease over time was also noted at both sites. Promising results for the control of the disease through application of fungicides were obtained only with Folicur particularly in combination with adjuvant Bacoil at Médine.

ACKNOWLEDGEMENTS

The authors extend their thanks to Messrs. Bissoon Mungroo of Le Val Nature Park and Mr. Francois Lagesse of Médine Sugar Estate for providing on-farm facilities. Sincere thanks are also expressed to Mr S.N Naidu, Director, Mr. D. Dumur, Assistant Director and Mr. R. Ramnauth, Biometrician of AREU for their help and support in the preparation of this paper.

REFERENCES

ANON. 1996. Folicur and Baycor: Mighty partners against black sigatoka in bananas. *Courier Agrochem*, 2nd issue: 4-7

SOOMARY S and BENI MADHU SP. 1998. The Mycosphaerella leaf disease complex (MLDC) of banana in Mauritius, pp 181-188 *in* Lalouette JA et al. eds. *Proc. of the second Annual Meeting of Agricultural Scientist* 12-13 August 1997, Reduit, Mauritius, Food and Agricultural Research Council.

STOVER RH and DICKSON JD. 1970. Leaf spot of bananas caused by *Mycosphaerella musicola*: method of measuring spotting prevalence and severity. *Trop. Agriculture, Trin*, 47, 289-302.

STOVER RH. 1971. A proposed international scale for estimating intensity of banana leaf spot. *Trop. Agriculture, Trin*., 48,185-96.

STATUS OF MAIZE DISEASES IN RODRIGUES

N Mawlah, JC Autrey **and** *S Saumtally*

Mauritius Sugar Industry Research Institute

ABSTRACT

Disease surveys were conducted in Rodrigues between 1980 and 1998 to determine the level of infection by various pathogens in maize. Smut Sphacelotheca reiliana was not encountered. Maize stripe virus was insignificant, although the vector Perigrinus maidis was present in most maize plantations. The incidence of rust Puccinia sorghi was low over the island. Leaf blight Helminthosporium turcicum and rust Puccinia polysora were light to moderate in some cultivars only. However the two diseases have the potential of reaching epidemic proportions under favourable conditions in susceptible varieties. Maize streak virus (MSV) was the most important disease encountered reaching levels as high as 100%. It was distributed all over the island but the sites with the highest incidence were mostly over the central ridge. The extent of the MSV has regressed from 1980 to 1998 because of the declining cultivation of maize. However the cultivation of resistant varieties such as MSIRI 3B is essential in a strategy to control MSV in Rodrigues.

Keywords: maize, *Zea mays*, maize streak virus, rust, *Sphacelotheca reiliana, Puccinia sorghi Helminthosporium turcicum, Puccinia polysora,* leaf blight, maize stripe, Rodrigues

INTRODUCTION

The island of Rodrigues is located 650 km to the east of Mauritius at latitude $19^{0}20^{'}$ south and longitude $63^{0}25^{'}$ east. Being 15 km long and 5-7 km wide, it has approximately 10,500 ha of land of which 4,000 can be cultivated. The island is characterized by a complete absence of flat land and a central ridge runs along most of its length. Owing to its relief, erosion is one of the most serious problems facing the island. The main crops grown on terraces across the slopes and valleys are maize, onion and garlic. The island supports a population of 35,000 people, and maize (*Zea mays* L.) was formerly its basic food which was also used as animal feed. Presently maize is gradually being replaced by rice, as not only the latter is readily imported into the island but it is also much easier to prepare. Furthermore the local population is abandoning agriculture and shifting to other sectors of the economy which have developed (Govinden et al.1996).

Though maize is grown in two periods, the first one starting in December - January and the next one in May - June, the two periods usually overlap. Some farmers plant in full-stand at a row spacing of 0.75 m and 0.30 m along the rows with 3 to 5 seeds per stand while others prefer mixed cropping as many of Rodriguans are still semi-subsistence farmers. Most crops are grown under rainfed conditions as irrigation facilities are lacking. Farmers make use of manure produced on the farm and inorganic fertilisers are generally not applied. The island relies on passage of tropical cyclones for rains. However maize plantations are often severely damaged or totally destroyed by the strong winds and high precipitation associated with cyclones.

Wiehe (1948) reported four pathogens on maize in Rodrigues: leaf spot (*Helminthosporium turcicum*) rust (*Puccinia sorghi*) smut (*Sphacelotheca reiliana*) and maize stripe, a virus disease. Orieux (1959) added southern rust (*P. polysora*) to the list. In 1973 heavy infection by streak (MSV) was a common occurrence in the island on maize varieties received as donation under the Food Relief Programme (Lallmohamed 1973). It was then decided to restrict the practice of importing maize for distribution. In 1975, occurrence of the virus disease was found to be sporadic, perhaps due to the prevailing drought conditions during that period (Lallmohamed 1975).

In the light of the above reports, it was felt necessary to have updated information on the level of infection by various pathogens in maize so as to design appropriate methods of control. Various surveys were carried out between 1980 and 1998 and the results are detailed in this paper.

MATERIALS AND METHODS

Disease Surveys

In 1980 an island wide survey was carried out. Forty three sites were surveyed, and only the local Rodriguan maize variety was cultivated. In 1985, two trials were established in Rodrigues, namely at Baie Malgache and at Maréchal to assess their reactions to prevailing diseases. Each trial consisted of 48 entries as follows:

Rodrigues pure lines	4
Single cross hybrids	2
Three way hybrids	2
Complex hybrids	7
South African hybrids	2
US pure lines	2
Mauritian ecotypes	11
Rodrigues ecotypes	10
Rodrigues local variety	1
CIMMYT and IITA genotypes	7

The Rodriguan local variety was included as a control. In August 1986, three trials were assessed at Petit Brûlé, Baie Malgache, and Baie aux Huitres. The trials comprised 60 entries each, which consisted of the following:

Rodriguan pure lines	8
Rodriguan ecotypes	8
Mauritian ecotypes	7
Rodrigues local variety	1
CIMMYT and IITA genotypes	18
South African hybrids	3
Complex hybrids	10
US pure lines	3
Three way hybrids	2

The Rodriguan local composite served as control.

In 1998 an island wide survey was carried out to determine the status of the maize disease situation. Thirty five sites were surveyed. Traditional farmers were still using their own ecotypes and others MSIRI 3B Composite which had been developed especially for Rodrigues (Rummun and Govinden 1996) having the advantage of being resistant to the MSV.

Methods of disease assessment

Leaf blight and rust were assessed on a six point scale (0-5) as devised by Ullstrup (1945):

0	Absence of disease
1	Slight infection
2	light infection
3	Moderate infection
4	Heavy infection
5	Very heavy infection

For MSV and maize stripe virus the percentage of plants infected were noted.

RESULTS

In 1980, the presence of rust, *Puccinia polysora,* was negligible at all 43 sites. Infection by leaf blight, *Helminthosporium turcicum*, was also slight at all the above locations with infection restricted to lower leaves only. The incidence of streak was as follows:

Less than 5% infection at 21 sites.
5 to 25% infection at 3 sites.
25 to 50% infection at 2 sites.
More than 50% infection at 5 sites.
100% infection at 4 sites.
Eight sites were free from infection.

The distribution and severity of MSV infection over the island in 1980 is illustrated in **Figure 1**. In the coastal areas and the western part of the island the disease was negligible while it was much higher in the central and eastern parts which are relatively higher in altitude. MSV was also noted on the following graminaceous weeds: *Cenchrus echinatus, Coix lacryma-jobi, Digitaria timorensis* and *Brachiara reptans.*

One case of maize stripe virus was detected at Oyster Bay and Petit Gabriel and at Mont du Sable two such infected plants were noted.

In 1985 observations were as follows in the two trials established in Rodrigues.

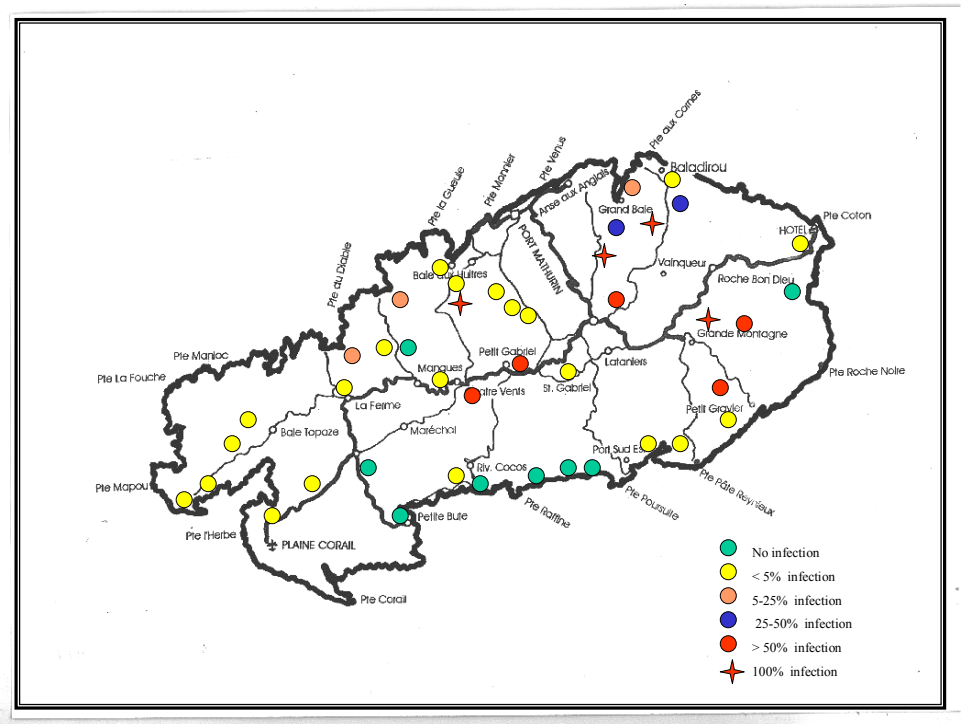
Baie Malgache

Maize leaf blight and maize streak virus were absent at the above site.

Maize rust (*P. polysora*) was common in all the entries. Rating varied from 1-2 to 3 in Rodriguan pure lines and in CIMMYT and IITA genotypes, 2 to 2-3 in single cross hybrids and in South African hybrids, 2 to 3 in complex hybrids, Mauritian ecotypes and in Rodriguan ecotypes, 2-3 to 3 in three way hybrids and in US pure lines. In the control Rodriguan local variety, the rating was 2-3.

Light infection of *P. sorghi* was also recorded on the control variety.

Figure 1 Incidence of Maize Streak Virus in Rodrigues - 1980



Maréchal

Leaf blight was not detected, and there was slight infection with rust, *P. polysora.* MSV was not present in Rodriguan pure lines, single cross hybrids, Mauritian ecotypes and Rodriguan ecotypes. Infection in the other entries is detailed in **Table 1**.

Table 1 Incidence of maize streak virus at Maréchal – 1985

Variety	% infection
Three way hybrids	
UR 14	15
Complex hybrids	
Rod 2 x Across 7635	5
M 100-14 x Across 7635	5
Pioneer hybrids	
Pioneer 482	5
Pioneer 6514	5
US pure lines	
H 99	5
CIMMYT & IITA populations and gene pools	
Genepool for STR	5
Population 24	10
Population 31	25
Across 7635	15
Control variety	
Rodrigues	10

Disease infection in 1986 was as follows:

Maize leaf blight

Rating of *H. turcicum* was 0.5 in three way hybrids, it varied from 0.5 to 1 in South African hybrids, 0.5 to 3 in Rodriguan ecotypes and in Complex hybrids, 0.5 to 3-4 in CIMMYT - IITA genotypes and Rodrigues pure lines, 1 to 3 in Mauritian ecotypes and was 1 in the local composite. Rust was absent in US pure lines.

Maize rust

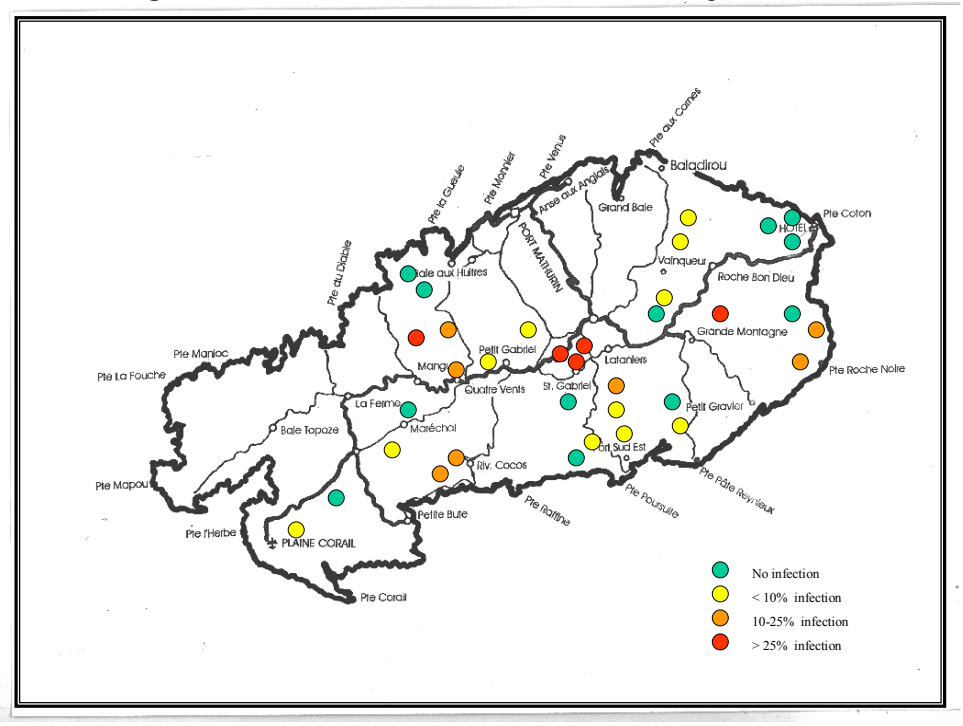
Rating for *P. polysora* varied from 0.5 to 3 in US pure lines , 0.5 to 4-5 in CIMMYT and IITA genotypes, 1-2 to 2-3 in South African hybrids, 2 to 3-4 in Mauritian ecotypes and in Complex hybrids, 2-3 to 3-4 Rodrigues pure lines and in the Rodriguan ecotypes. It was 2-3 in three way hybrids and 3 in the local composite.

Maize streak virus

MSV infection ranged from 0 to 29% in the Rodriguan ecotypes, 0 to 4.8% in Mauritian ecotypes, 0 to 47% in CIMMYT and IITA genotypes, 7 to 24% in South African hybrids, 0 to 5.2% in three way hybrids, 0 to 28.3% in Rodrigues pure lines, 0 to 46% in Complex hybrids, absent in US pure lines and 3.6% in the local composite.

In 1998 during the island wide survey out of 35 fields visited, 69 % of them were planted with the farmers own seeds, while the remainder was covered with the MSIRI 3B Composite. The most severe disease was MSV, while the fungal diseases were of minor importance. Severity of the virus infection in 1998 is illustrated in **Figure 2**.

Figure 2 Incidence of maize streak virus in Rodrigues -1998



Eighty two percent of the maize plantations consisting of the resistant maize (MSIRI 3B composite) were free from infection and in the remaining 18%, infection by streak was very light, while among those fields planted with the farmers own seeds, only 12% escaped infection, 38% of them had infection less than 10%, in 29% of the fields infection was 10-25% and above 25% in the remaining fields. Traces of *H. turcicum* was detected in 20% of fields and in 8% traces of *P. polysora* was present. Only 1 case of maize stripe virus was detected at Le Chou.

DISCUSSION

Smut of maize was not detected in any of the surveys. As for the other fungal diseases namely leaf blight and rust, they were of significance in some cultivars only. In the variety trials, moderate to heavy infection was noted in some varieties indicating that these two fungi have the potential to reach epidemic proportions under favourable conditions in susceptible maize varieties. In Mauritius moderate infection of leaf blight in varieties UR 14, Pioneer 432 and ZS 5206 caused yield reduction of 38, 64 and 23% respectively (Mawlah 1990). In a similar trial, using fungicide Bitertanol against *P. polysora* in variety UR 14, 69% increase in yield was obtained under conditions of very heavy infection (Autrey 1988). Rust and leaf blight are potentially damaging diseases in Rodrigues and should not be overlooked. However it must be noted that the wider than normal spacing adopted by the Rodriguan farmer so as to carry out mixed cropping does not allow the crop canopy to retain the necessary relative humidity for the fungi development as was the case in the trials established.

MSV was the most important disease of maize. Various levels of infection were encountered. In some plantations, the infected plants were stunted whereas in others the plants tolerated the disease, producing cobs. In Mauritius, yield reductions due to MSV was in the order of 24 and 28% in hybrids United 530 and Anjou 360 for infection levels of 40 and 50% respectively (Ricaud and Felix 1979), while in one field of United 530, a severe attack resulted in total loss of the crop (Autrey and Ricaud 1982). Further the following members of the Gramineae have been found naturally infected with MSV locally: *Coix lacryma-jobi, Cenchrus echinatus, Brachiaria reptens, B. eruciformis, Panicum maximum, Paspalum conjugatum, Digitaria timorensis, D. horizontalis, D. didactyla and Saccharum* hybrids (Ricaud and Felix 1978).

On examining the disease situation from 1980 to 1998, it can be concluded that MSV level has regressed. This is mostly due to the fact that cultivation of maize has been gradually declining. The area under cultivation is now 320 ha as compared to 1800 ha in 1986 (Govinden et al. 1988). Furthermore the clearing of wasteland and the resulting development has led to a decrease in the number of alternative hosts. Another important factor could be the introduction of the MSIRI 3B composite which is resistant to the virus (Rummun and Govinden 1996).

Only one case of maize stripe virus was noticed at Le Chou in 1998. However the vector of this virus *Perigrinus maidis* was presented in almost all maize plantations. It is therefore important to monitor the evolution of this virus disease and most importantly new varieties should be evaluated before commercial cultivation over the island.

Non-pathogenic problems that some traditional farmers have a tendency to associate with diseases are leaf chlorosis and stunting of plants due to a lack of fertilisers, rolling of leaves caused by drought and leaf scorch due to heat. The wide spacing practiced by the farmers and the low soil coverage by plants allow the rapid development of weeds that colonise the space available when no other crop is grown. This competition has a negative effect on the maize crop as well as harbouring diseases and insect vectors. Good cultural practices and sanitation are important to reduce the impact of diseases on maize in Rodrigues.

CONCLUSION

Maize diseases occurring in Rodrigues could be a serious handicap to the farmers if susceptible varieties are grown. Composite MSIRI 3B is a valuable cultivar in a strategy to control MSV. This variety should be multiplied and made available to local farmers. The exploitation of this cultivar should help to boost production in Rodrigues. New technologies (fertilisers, herbicides, irrigation) and integrated development packages (e.g. availability of inputs and of credit) as suggested by Rajkomar et al *(*1996), have to be made available to the farmers as well.

ACKNOWLEDGEMENT

We would like to thank officers of the Agricultural Services of Rodrigues for their collaboration during the visits in the various sites over the island.

REFERENCES

AUTREY JC. 1988. Epidemiological studies on *Puccinia polysora,* its economic importance and measures adopted for its control in Mauritius. p 180-200. *In*: *Proc. of the 2nd Eastern, Central and Southern Africa Regional Maize Workshop,* Harare, Zimbabwe. 1987.

AUTREY JC and RICAUD C. 1982. The comparative epidemiology of two diseases of maize caused by leafhopper-borne viruses in Mauritius. p 277-285 *In*: *Proc. Plant Virus Disease Epidemiology Conference*.. Oxford 1981.

GOVINDEN N, RAJKOMAR B, BERTHELOT PB and MUNDIL K. 1996. Agriculture in Rodrigues. I. Present Situation. *Revue agric,. Sucr. Ile Maurice*. 75(3): 1-8.

GOVINDEN N, RAMASAMY S and TOLBIZE JW. 1998. *Maize in Rodrigues – Production problems*. Occasional Report No. 18, MSIRI.

LALLMOHAMED GM. 1973. Report of the Plant Pathologist's visit to Rodrigues, December 1972.

MAWLAH N. 1990. Studies on Northern corn leaf blight in Mauritius. BSc Thesis. University of Mauritius. 109 pp.

ORIEUX L. 1959. Report of the Plant Pathologist's visit to Rodrigues, November 1959.

RAJKOMAR B, BERTHELOT PB, MUNDIL K and GOVINDEN N. 1996. Agriculture in Rodrigues. III. Typology of farmers. *Revue agric,. Sucr. Ile Maurice*. 75 (3): 15-21.

RICAUD C and FELIX S. 1978. Sources and strains of streak virus infecting graminaceous hosts. *Proceedings, International Congress of Plant Pathology* 3, 23 (Abstract).

RICAUD C and FELIX S. 1979. Identification and relative importance of virus diseases of maize in Mauritius. P 105-109. *In Proc. 2nd S. Afr. Maize Breeding Symp*. March 17-19, 1976.

RUMMUN K and GOVINDEN N. 1996. Progress achieved in the breeding of Maize in Mauritius. *Revue agric,. Sucr. Ile Maurice*. 75(2): 28-32.

ULLSTRUP AJ. HOPPE PE, ELLIOT C. 1945. Report of the committee on methods for reporting corn disease ratings. U. S. Department of Agriculture, Division of Cereal, Crops and Diseases. 5 pp.

WIEHE PO. 1948. The plant diseases and fungi recorded from Mauritius. List of plant diseases from Rodrigues, p 19. Mycological papers 24. CMI. Kew, Surrey, UK

DETECTION FROM SOIL AND DISTRIBUTION OF *Ceratocystis paradoxa* MOREAU, CAUSAL AGENT OF THE PINEAPPLE DISEASE OF SUGARCANE.

Y Moutia* and *S Saumtally

Mauritius Sugar Industry Research Institute

ABSTRACT

Two methods were compared for the isolation from soil of the fungus Ceratocystis paradoxa, causal agent of pineapple disease of sugarcane. The semi-selective V8-A medium permitted both a qualitative and a quantitative assessment and colonies characteristic of the pathogen were observed within two days. The recovery power of the medium was lowered when the spore concentration was high probably due to crowding of spores and aggregation. The range of spore densities detected was 0 to 9963/g of soil. Fifty percent of all fields sampled were infected and most had less than 500 spores/g of soil. The presence of contaminating fungi in the medium, despite the presence of fungicides, did not affect the enumeration of colonies of C.paradoxa provided readings were taken within 2-3 days after incubation. The tissue bait technique was a qualitative assay and results were available within two weeks. The two methods were comparable with 82% agreement between the results. However, the baiting technique appeared more sensitive than the V8-A medium. The pathogen was detected in all regions surveyed in Mauritius, with predominance in the centre, east and south. Furthermore, the pathogen was present within a wide range of soil pH (4.2 to 7.9) and soil types.

Keywords: sugarcane, *Ceratocystis paradoxa*, V8-A semi-selective medium, soil pH, tissue bait, pineapple disease, Mauritius.

INTRODUCTION

Pineapple disease of sugarcane caused by the ascomycetous fungus *Ceratocystis paradoxa* (Dade) Moreau belonging to the order Microascales, is an important rot of sugarcane cuttings. The disease affects sugarcane setts in the first weeks after planting leading to poor germination of buds and emergence of young shoots. As a result, gappy stands are evident and young crops have a patchy and uneven appearance. The fungus is essentially soil-borne, being transmitted to cane setts via two types of spores: thin-walled cylindrical conidia (6-24 um x 2-5.5 um) and thick-walled oval chlamydospores (10-25 um x 7.5-20 um). The latter ensures the long-term survival of the pathogen in the soil. Infection occurs mainly through the cut ends but also through wounds caused by insects and through cracks in cuttings. The fungus spreads rapidly through the parenchyma, which becomes red and breaks down leading to a hollow and blackened interior. In the early stages of rotting, the disease may be diagnosed by a strong odour of over-ripe pineapple.

Factors such as excessively deep planting, wet or dry soil and low soil temperature delay germination of buds and emergence of young shoots and hence favour infection by the fungus. The longer the buds take to germinate and emerge, the more prone the cuttings are to attack by the pathogen.

The economic importance of the disease is not negligible. When shoot population is reduced, direct yield losses result. Furthermore, gappy stands necessitate costly replanting or recruiting and weed problems may also result if leaf canopy development is retarded. Control is a priority specially where soil inoculum level is high through the amelioration of conditions that favour germination of buds and emergence of young shoots (e.g. good quality cuttings, adequate irrigation and right planting time). In addition, the use of protective fungicides is recommended. The ends of cuttings are dipped in a fungicidal solution either as a cold dip or the fungicide may be incorporated into the water tank at the time of the hot water treatment. In Mauritius such treatments have been in use since the 1950's

(MSIRI. 1954 ; Antoine 1956). The most commonly used fungicides are Benlate (benomyl), Tilt (propiconazole) and Topsin M (thiophanate methyl) as reported by Autrey (1974) and Wismer and Bailey (1989). Varietal resistance has been reported in some local and foreign varieties (MSIRI 1997).

The pathogen has been isolated from the soil by two main methods: a sugarcane disc technique (Aberdeen and Patil-Kulkarni 1969) and a selective medium (Rashid and Trujillo 1974). The pathogen has been found to occupy mainly the top 25 cm of the soil profile where sugarcane setts are usually planted (Aberdeen and Patil-kulkarni 1969). In Hawaii, Rashid and Trujillo (1974) have reported spore densities of up to 3875/g of soil. The purpose of this study was to compare two detection methods namely tissue bait and the V8-A semi-selective medium. In parallel, the extent of soil infection on an island-wide basis was assessed.

MATERIALS AND METHODS

V8-A semi-selective medium

The following semi-selective medium after Rashid and Trujillo (1974) was used.

Component	Unit	Quantity
Tomato juice	*ml*	200
Distilled water		800
Calcium carbonate	*g*	1.0
Agar Technical (no 3)		20
Oxgall powder		0.8
PCNB (Pentachloronitrobenzene) WP 75		0.66
Streptomycin sulphate		0.2
Tetracycline hydrochloride		0.05

The pH was 6.35. Antibiotics, fungicides and Oxgall powder were added after autoclaving the medium (121 ^{o}C for 15 minutes) and allowing it to cool to 45 ^{o}C.

Viability test

The viability of chlamydospores of *C. paradoxa* was investigated by plating a spore suspension on 1% sucrose agar and incubation at 28 ^{o}C for 18 hours. Petri dishes were observed under the microscope at x200 magnification. Several fields of view were inspected. The number of spores that had germinated together with those that had not after that lapse of time were then counted. The percentage germination was then derived from these raw values.

Recovery test

The recovery power of an isolation medium determines its efficacy and usefulness. The medium under study was tested for its efficacy in the isolation of propagules of *C. paradoxa*. Spores, mainly chlamydospores were harvested from infected stalks of variety M 261/78 and transferred to a Corning tube containing 14 ml of sterile distilled water. This stock preparation was vortexed for 2 minutes to separate the spores. A suspension was then prepared by dilution of the stock to give a concentration of 4000 spores/ml. Different volumes of this diluted preparation namely 6.25, 12.5, 25, 50 and 100 ml were then added to Petri dishes and swirled in 15 ml of the medium to give a theoretical number of 25, 50, 100, 200 and 400 spores per Petri dish. Three replicated plates were made for each volume. The Petri dishes were then incubated at 28 ^{o}C for 3 days after which they were assessed for the number of colonies present.

Soil sampling

Sixty-one sugarcane fields from different regions of the island were surveyed. Soil was collected with the aid of a small spade. A single sample of about 150 g of soil was removed from furrows over a depth of about 20 cm at each site and transferred to a clean plastic bag. The sample was labelled and the location and field number noted. Soil samples were then taken to the laboratory for the assay.

Sample preparation and incubation

The soil from each bag was thoroughly mixed. A sub-sample of 20 g was weighed and added to 40.5 ml of sterile distilled water containing 0.05% Tween-20 in a 250 ml labelled Erlenmeyer flask. Tween-20 was added to help in the release of spores adhering to soil particles. The flasks were capped with aluminium foil and agitated on a shaker (Gallenkamp orbital shaker) at 100 rpm for 2 hours. One millilitre of the soil suspension was pipetted and transferred to 9 ml of sterile distilled water in a Universal tube. After thoroughly shaking the tube, 0.5 ml of the suspension was transferred into a labelled, sterile Petri dish and swirled in 15 ml of the medium. This was replicated three times. Petri dishes were then incubated at 28 ^{o}C in the dark for 3 days after which they were removed from the incubator and the number of black colonies typical of *C. paradoxa* counted. Doubtful colonies were checked by microscopic examination (x 400) for the presence of characteristic spores.

Soil pH

The soil pH was determined according to the method described by Brady (1990) on the same 1:2 soil solution prepared for isolation of *C. paradoxa*.

Tissue-bait technique

Sugarcane cuttings of the variety M 261/78, which is known to be highly susceptible to the pathogen (MSIRI 1997), was used as bait. A single 3-eyed cutting was used for each sample. With the aid of a cork borer having an internal diameter of 7 mm, a hole was made in the internodal tissue to a depth of 1 cm. The plug of tissue was removed and about 0.3 g of soil from a given sample was deposited inside the hole with the aid of a small spoon. The hole was then sealed by means of scotch tape and the cutting was placed in a plastic bag. Incubation was for 3 weeks at 25 ^{o}C in the dark. The spoon was flamed between samples to prevent cross contamination. Presence of the pathogen was determined by slicing the cutting longitudinally across the hole and examination of the tissues. Slides were prepared for microscopic examination to confirm the presence of the pathogen.

Slide preparation for microscopic examination

A slide was prepared by using a piece of scotch tape and pressing it onto the suspected area. The tape was then placed on a drop of water on a slide. A drop of water was added on top of the tape followed by a cover slip. The preparation was observed under the light microscope at x200 or x400.

RESULTS

Viability test

Germination of spores was easily determined by microscopic examination. At x200, a germ tube was observed protruding from the spore wall. Any spore having a germ tube was counted as germinated. Out of a total of 139 spores, 41 had germinated after 18 hours representing 29.5%.

Dilution and recovery

Colonies of *C. paradoxa* appeared two days after incubation. They were initially whitish, measuring about 5 mm in diameter. One or two days later, the colonies turned black due to the production of

chlamydospores, which are heavily pigmented, when mature. Colony counts are shown in **Table 1**. The recovery % varied between 27 and 46 being higher at lower spore concentrations

Table 1 Efficacy of V8-A semi-selective medium in the detection of *C. paradoxa*

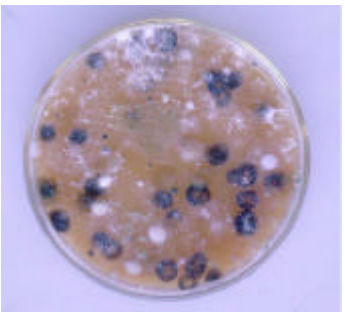
Number of spores expected	Number of colonies observed ± S.E.	Recovery % (observed x 100 / expected)
25	11.0 ± 0.6	44.00
50	23.0 ± 3.1	46.00
100	27.0 ± 1.5	27.00
200	56.3 ± 7.4	28.17
400	109.5 ± 3.5	27.38

Soil assay

V8-A semi-selective medium

Dark colonies characteristic of *C. paradoxa* appeared after two days (**Plate 1**).

Plate 1



The presence of a wide range of contaminating fungi was also noted and some identified as *Fusarium spp*, *Pythium spp* and *Penicillium spp*. Bacterial colonies were absent. *C. paradoxa* was present in all five regions surveyed and out of 61 soil samples assayed, 25 were infected. The population density of *C. paradoxa* ranged from 14 to 9963/g of soil. Although the number of fields surveyed varied in the different regions, there was a tendency for a larger number of infected ones in the east, south and centre. The spore density of 17 fields (28%) was in the range of 1-500/g of soil whereas two fields (3%) had densities in the 501-1000/g range. Three fields (5%) had densities of 1001-1500/g and one field (1.6%) each in the range 1501-2000, 2001-2500 and 9501-10000/g of soil. Results of the soil assay are graphically shown in **Figure 1.**

Tissue bait

In several cases the pathogen had invaded the tissues surrounding the inoculation point. A greyish mycelium was sometimes visible inside the hole. Infection was also characterised by a reddening of tissues and the presence of dark brown/black chlamydospores as identified by microscopic examination. The fungus was detected in the five regions tested. Out of 61 field samples tested, 30 were positive for the presence of *C. paradoxa*. Results are graphically shown in **Figure 2**.

Distribution of the pathogen and soil pH

The soil pH varied from 4.2 to 8.2 but the pathogen was found in soils with pH values in the range of 4.2 to 7.9. No fungus was found above a pH of 7.9 with a majority of fields infected (78.6%) found in the range of pH 5-6. *C. paradoxa* was found in the following soil types: L2, L3, P1, P3, B1, H2 and F1 (Arlidge and Wong You Cheong 1975).

Figure 1 Frequency of fields with different soil inocula as determined by the use of the V 8-A semi selective medium

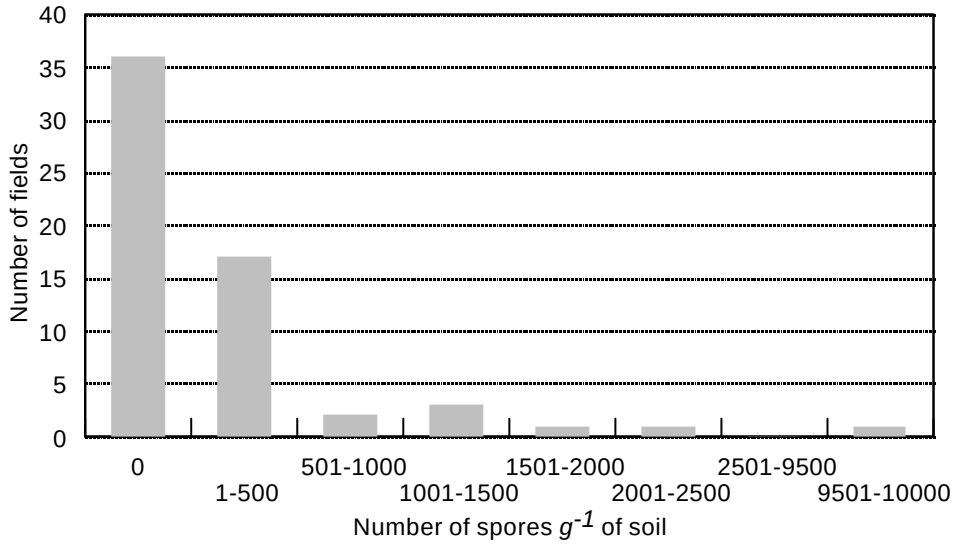
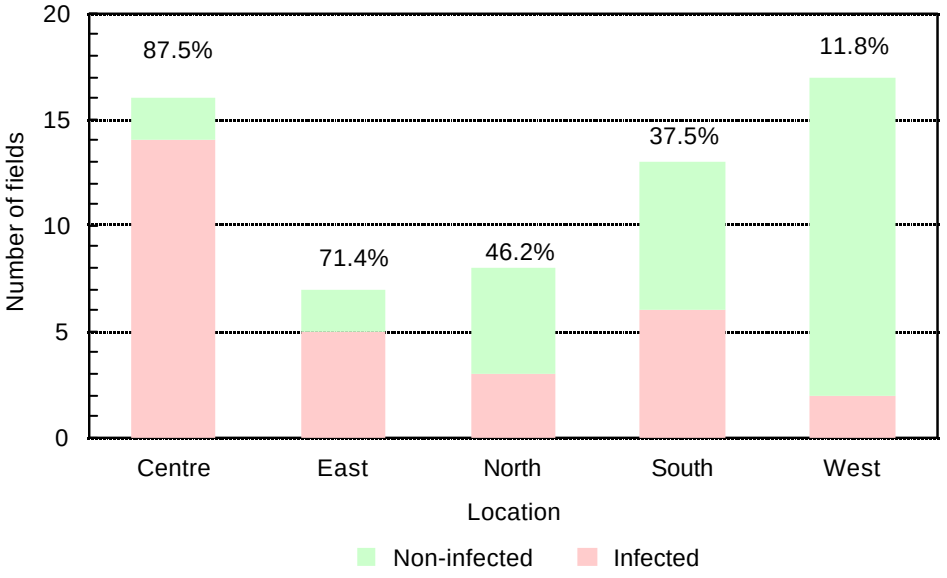


Figure 2 Dectection and distribution of *C.paradoxa* in sugarcane fields by the use of a tissue bait technique



DISCUSSION

It is well known that out of the millions of spores produced by fungi, only a certain percentage is viable and this forms the inoculum potential of the pathogen. The viability of spores is very variable. Assessment of the viability of spores of *C. paradoxa* gave quite low values but knowing the large number of spores produced by the pathogen, the final soil inoculum is significant. Since only 30% of spores had germinated after 18 h, it is also possible that the spores followed a cycle of germination and that not all spores germinated simultaneously. Germination would best be monitored over a longer period for an accurate determination of spore viability. It is also possible that self inhibitors were active in the presence of large spore aggregates and repressed germination as has been found for the rust fungus (Allen 1955, 1965).

The recovery power of the V8-A medium was determined by the use of a range of spore dilutions. At high spore concentrations, the discrepancy between expected and observed values was large. It was found that the ideal dilutions should be such that the total number of colonies in a Petri dish does not exceed 50. Crowding of spores or aggregation caused underestimation. As a result, spores that are too close do not form distinct colonies. Thus, it is desirable when testing soil samples to dilute the soil suspension to avoid crowding and underestimation. Low dilutions should also be avoided, as the sensitivity of the medium would then be compromised.

The detection of a particular soil-borne pathogen is not simple as the soil harbours a wide array of microorganisms mainly saprophytic ones. The micro flora consists mainly of bacteria, actinomycetes, fungi and algae. The development of a fully selective medium is therefore a challenge and a time-consuming procedure. Tainter (1992) has described some selective media for the isolation of different *Ceratocystis spp*. from soil whilst Rashid and Trujillo (1974) have devised a semi-selective medium particularly for.the isolation of *C.paradoxa*. In this study, the proposed medium has been put to test and evaluated against a wide range of soils, which encompassed a large array of soil microorganisms. The medium proved adequate for the isolation of the pathogen. Colonies characteristic of *C. paradoxa* appeared within 2 days. Moreover, V8-A medium favoured the rapid production of chlamydospores, which facilitated the identification of colonies of *C. paradoxa*. The V8-A semi-selective medium allowed both a qualitative and a quantitative estimate of the population of *C. paradoxa* to be made. However, it would be desirable to make the medium more selective as the presence of contaminants could lead to underestimation of colony counts. The incorporation of selective fungicides that would allow the germination and growth of *C. paradoxa* but inhibit the fungal contaminants needs to be tested.
As it is the first time such a survey is carried out in Mauritius, it is not possible to make comparisons with past results. However, the results confirmed the belief that the pathogen is well disseminated around the island independently of soil pH and soil type. Soil population density of *C. paradoxa* varied considerably between fields and regions as would be expected with a soil-borne pathogen. It is interesting to note that the level was not alarmingly high in most fields. Past experiments in the glasshouse revealed that a population of 1000 spores/g of soil could be considered as the threshold inoculum level that could cause field problems (MSIRI 1998). Only 5 fields out of 61 had this threatening level. One field had a very high spore density of 9963/g of soil and this field had been mechanically harvested prior to soil sampling. It is not known why such a high inoculum level was present. It is possible that chips of sugarcane stalks, blown off by the fan of the mechanical harvester, were scattered in the field and acted as a suitable medium for the development and multiplication of the pathogen after harvest. Soil sampling before and after mechanical harvest from the same fields would help in the understanding of this phenomenon.

The tissue bait technique was a modification of Aberdeen and Patil-kulkarni's method (1969). It was a qualitative test indicating the presence or absence of the pathogen. In most cases resort to microscopic examination was needed to confirm the presence of the fungus in the sugarcane setts. Although a longer time span was required for this assay, it appeared more sensitive than the V8-A medium. Out of 61 fields surveyed, 30 were found infected by this technique whilst the V8-Agar medium detected only 25 infected fields. The absence of dilution in the tissue bait technique probably improved its sensitivity as compared to the V8-A medium, especially in the presence of low spore loads. However, it was clear that enough time should be allowed for the multiplication of the fungus inside the cuttings so that low initial undetectable soil inocula could be more readily detected by microscopic examination. This explains why in a few cases, the pathogen was detected by the V8-A medium but not by the tissue bait technique.

The soil pH is known to be important in the occurrence and severity of plant diseases caused by certain soil-borne plant pathogens such as clubroot of crucifers (*Plasmodiophora brassicae*) and common scab of potato (*Streptomyces scabies*). In clubroot of crucifers, the pathogen is more prevalent and severe at about pH 5.7 but is completely checked at pH 7.8 whilst in common scab severity of the disease is greater in the pH range of 5.2 – 8.0 but negligible below pH 5.2. In many of these diseases, the effect of soil acidity seems to be principally on the pathogen, although in some, a weakening of the host through altered nutrition that is induced by the soil acidity may affect the incidence and severity of the disease (Agrios, 1988). It would be premature to make conclusions on the importance of soil pH and soil type in the distribution of *C. paradoxa* and the severity of the pineapple disease. In the future, more fields would have to be surveyed and severity of the disease assessed in the glasshouse on soils amended to give different pHs.

CONCLUSION

As the pathogen can be isolated from soil, it is important to establish a reliable sampling strategy that should take into account the size of fields. Sampling should aim at reducing to a minimum the inherent variability associated with the distribution of a soil-borne pathogen. Samples should be taken such that they give a true indication of the extent of soil infection for a given field. The techniques that have been developed in this study would henceforth allow the monitoring of soil population dynamics and the understanding of the ecology of the pathogen. Moreover, the different isolates collected would be useful for testing for the possible presence of strains of the pathogen. In the long-term, these findings would be instrumental in devising control strategies.

ACKNOWLEDGEMENTS

The authors would like to thank the Director and Deputy Director of the MSIRI for their comments and permission to publish this paper. The support of Mrs R. Migale and Mr R. Begue is also acknowledged for the visual presentation.

REFERENCES

ABERDEEN JEC and PATIL-KULKARNI BC. 1969. The measurement of the concentration and distribution of *Ceratocystis paradoxa* (De Seynes) Moreau in soil. *Australian Journal of Agricultural Research* 20: 843-856.

ALLEN PJ. 1955. The role of a self-inhibitor in the germination of rust urediniospores. *Phytopathology* 45: 259-266.

ALLEN PJ. 1965. Metabolic aspects of spore germination in fungi. *Annual Review of Phytopathology* 3: 313-342.

AGRIOS GN. 1988. Environmental effects on infectious plant disease development: Effect of soil pH. p 152. In Agrios G.N. ed.: *Plant Pathology* 3rd editionAcademic Press Inc, San Diego, California.

ANTOINE R. 1956. Cane diseases. Pineapple disease. *Mauritius Sugar Industry Research Institute Annual Report* 1956. p 59.

ARLIDGE EZ and WONG YOU CHEONG Y. 1975. *Notes on the land resources and agricultural suitability map of Mauritius, 1: 50 000*. Reduit: Mauritius Sugar Industry Research Institute. 138 p. Occ. Pap. Maurit. Sug. Ind. Res. Inst. 29.

AUTREY LJC. 1974. Control of *Ceratocystis paradoxa* (Dade) C. Moreau in sugarcane by the systemic fungicide benomyl. Special study, B.Sc. Degree Botany. University of London. 39 p.

BRADY NC. 1990. Soil Reaction : Acidity and alkalinity. p 230. In Brady N.C. ed. *The nature and properties of soils*. Macmillan Publishing Company. New York.

MSIRI *see under* Mauritius Sugar Industry Research Institute

MAURITIUS SUGAR INDUSTRY RESEARCH INSTITUTE. 1954. Hot water treatment. *Mauritius Sugar Industry Research Institute Annual Report* 1953. p 14.

MAURITIUS SUGAR INDUSTRY RESEARCH INSTITUTE. 1997. Sugar Cane. Crop Protection : Diseases. *Mauritius Sugar Industry Research Institute Annual Report* 1996. p 36.

MAURITIUS SUGAR INDUSTRY RESEARCH INSTITUTE. 1998. Sugar Cane. Crop Protection : Diseases. *Mauritius Sugar Industry Research Institute Annual Report* 1997. p 33.

RASHID AR and TRUJILLO EE. 1974. Ecology of *C. paradoxa* in field soils. Experimental Station *Hawaii Sugar Planters Association Annual Report* 1974. p 50.

TAINTER FH. 1992. Ceratocystis. p57. In: Singleton L.L., Mihail JD and Rush CM. ed. *Methods for research on soilborne phytopathogenic fungi*. APSpress, St Paul, Minnesota.

WISMER CA and BAILEY RA. 1989. Pineapple disease. p 145-155. *In*: Ricaud C, Egan B.T, Gillaspie Jr A.G and Hughes C.G. ed. *Diseases of Sugarcane. Major diseases*. Amsterdam, Elsevier Science Publishers B.V.

GREGARINE (PROTOZOA: APICOMPLEXA: EUGREGARINIDA) INFECTIONS IN SUGAR CANE WHITE GRUBS (COLEOPTERA: SCARABAEIDAE) IN MAURITIUS

M Govendasamy* and *S Ganeshan

Mauritius Sugar Industry Research Institute

ABSTRACT

A protozoan disease was first detected in 1985 on the white grub Phyllophaga smithi Arrow (Coleoptera: Scarabaeidae). Several studies were carried out to establish its distribution over the island and its incidence in other white grub species. Two apparently different gregarines (Apicomplexa: Eugregarinida) were found infecting second and third instar larvae of P. smithi and third instar larvae of Adoretus sp. Approximately 70% of the P. smithi examined were infected. The possible regulating role of gregarines in bringing previously high damaging populations of P. smithi to their present low levels is considered. The presence and abundance of these gregarines were correlated with fat body reserve of larvae of P. smithi collected from different soil types.

Key words: Gregarines, white grubs, *Phyllophaga smithi*, sugarcane, distribution, Mauritius.

INTRODUCTION

Several species of white grubs (Coleoptera: Scarabaeidae) are associated with sugar cane in Mauritius, namely *Phyllophaga smithi* Arrow (Melolonthinae), *Heteronychus licas* Klug., *Alissonotum piceum* Fab. (Dynastinae) and *Adoretus* spp. (Rutelinae). *P. smithi* and *H. licas* are considered to be the most important. Another dynastine, *Temnorrhynchus truncatus* Klug., is commonly encountered in sandy grasslands in coastal areas.

P. smithi was introduced into Mauritius, probably around 1906 (de Charmoy 1912), and rapidly reached epidemic levels. Severe infestations occurred in several regions with populations of more than 700 000 grubs per hectare (150-200 larvae per stool). Severely infested fields were utterly destroyed or yielded less than 25 tonnes cane per hectare (Moutia and Mamet 1946).

In the earlier part of this century, several parasitoid species (Scoliidae and Tiphidae) from various parts of the world were introduced and released for the control of *P. smithi* (Greathead 1971). The population of *P. smithi* has now reached innocuous levels yet this decline cannot be attributed solely to the parasitoids. Sporadic attacks by *H. licas* occur in sugarcane fields but seldom become extensive. *H. licas* was first identified in Mauritius in 1981 but its presence dates far back, probably having been confused with *A. piceum* (MSIRI 1982).

In 1985 gregarine infections were observed in field-collected larvae of *P. smithi* (Vercambre and Robert 1985). Soil-inhabiting gregarines are known to infest the digestive tracts and body cavities of invertebrates. Some are commensals whilst some are parasitic, producing weak disease symptoms with long term detrimental effect, or can be lethal to the host. Generally, gregarines inhabiting the midgut are less pathogenic than those inhabiting the gastric caeca (Tanada and Kaya 1993).

Gregarines occur in the soil as mature oocysts which, once ingested by larvae, are acted upon by the digestive juices in the insects' alimentary tract. Sporozoites emerging from the oocyst attach themselves to the midgut epithelial cells or enter the haemocoel and become trophozoites. They develop into sporonts which undergo syzygy forming a cyst (gametocyst). The gametes fuse to form a zygote, which secretes a thick membrane to form an oocyst (Tanada and Kaya 1993; Undeen and Vavra 1997). Larvae of the above-mentioned species were collected to check for the presence of gregarines. Gregarine incidence and externally visible fat deposition were correlated with weight of larvae of *P. smithi* collected from various soil types.

MATERIALS AND METHODS

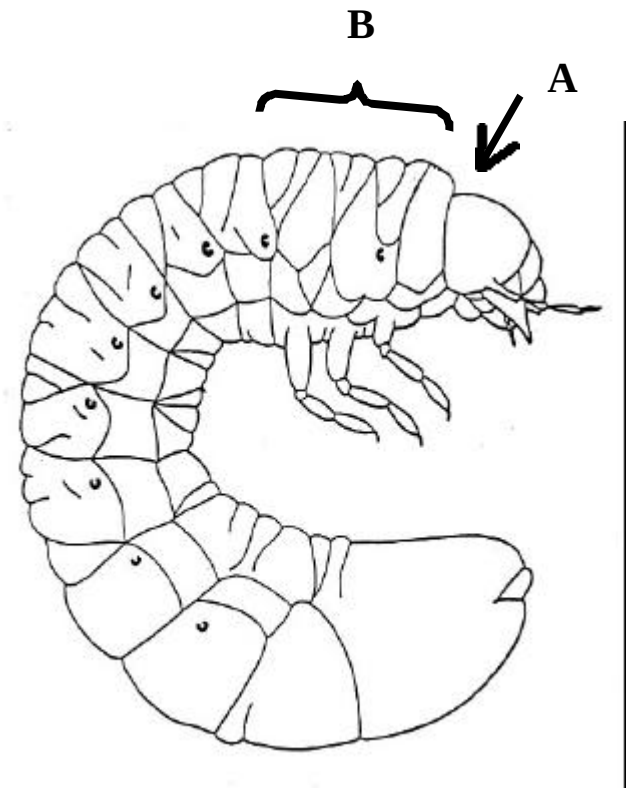
Soil sampling for larvae was carried out in various localities between 1990 and 1998. At each sampling point within a field, a hole 50 cm across a cane row x 50 cm wide and 30 cm deep was dug as close as possible to the sugar cane stool. All larvae and adults of white grubs found in the hole were collected in small plastic boxes (6 x 4 cm, diam) with some soil. A maximum of five larvae were placed in a box because larvae can hurt each other when crowded. The larvae were brought to the laboratory where they were dissected, as far as possible, on the same day to avoid mortality.

The larvae were weighed individually. The fat content of each larva was assessed visually, prior to dissection, and rated as follows:

1: fat accumulated at posterior end only
2: fat extending to half body length
3: fat covering 75% body length
4: fat over the whole body, imparting a creamish colour (near pupation)

The head capsule was cut off with a pair of scissors and the contents of the midgut squirted out by pressing within region B (**Figure. 1**) thereby expelling the dark brown digestive fluid. The fluid was examined for sporonts and the foregut was examined for the presence of spherical oocysts. Only occasional attempts were made to examine the anal part for the presence of oocysts.

Figure 1 Schematic diagram of a larva showing region where head was severed (A) and region where alimentary gut contents squirted out (B).



Fat content was correlated with gregarine incidence based on an estimate of the number of sporonts (single or in syzygy). In 1999 only the presence of gregarines was noted.

Adults collected in light traps were also dissected to assess the status of gregarine infections. The presence of sporonts or cysts, if any, within the whole alimentary system was observed.

Attempts were made to isolate the gregarines either by transferring the gregarines from the digestive juices into N5 or N10 brine solutions, or by centrifuging to see if gregarines could be separated and isolated for identification purposes.

RESULTS

Between 1990 and 1995, 675 late stage L3 larvae of *P. smithi*, 75 of *H. licas*, 14 of *A. piceum*, 7 of *Adoretus spp*. and 15 of *T. truncatus* were dissected. Gregarines were encountered in 77% of the larvae of *P. smithi*. None of the larvae of the other species showed infection with the exception of three L3 *Adoretus* sp. in one locality in 1995 which had different-shaped gregarines.

No gregarines were found in the 33 adult *P. smithi*, 8 *H. licas*, 3 *A. piceum*, 1 *T. truncatus* and 1 *Adoretus spp*. dissected between 1992 and 1996. There was no correlation between fat content and presence of gregarines in *P. smithi* larvae. In 1999, 95% of the 138 L3 larvae of *P. smithi* collected showed gregarine infections. According to descriptions given by Poinar and Thomas (1978), Tanada and Kaya (1993) and Undeen and Vavra (1997), the gregarine from *P. smithi* belongs to the order Eugregarinida. Its identification was not possible as attempts to isolate it was not successful. The sporonts bulged within minutes outside the digestive fluid and disintegrated when manipulated.

DISCUSSION

It would seem that gregarines are closely associated with *P. smithi*. This long-standing infection may have had a detrimental effect on the larvae with time. There was, however, no correlation between presence of gregarine, body fat within the larvae, and body weight of larvae. Nor was there any correlation in the occurrence of gregarines with different soil types in the 1990 study. This suggests that gregarines are widely dispersed in our soils. Vercambre (1990) found, in his studies in Mauritius on *P. smithi*, a general tendency of reduced body fat content with increasing number of gregarines from 235 L3 stage field-collected larvae. It is to be noted that *P. smithi* was scarce in soils everywhere in 1998-1999 yet gregarine infection was high. This indicates that gregarines occur abundantly in the soil. No gregarines were recovered from *H. licas and A. piceum* larvae or adults during those studies or by Vercambre and Robert (1985). Marchal (1986), however, had observed the presence of another gregarine species with a level of parasitism of 3.8% from 1303 L3 larvae of *H. licas* collected at Bassin in 1986. It is worth noting that this finding was based on visible cysts appearing through the transparent tegumen and not on the presence of sporozoites or sporonts.

A different form of gregarine was observed in 1995 on *Adoretus sp*. Further verifications of the gregarine status of *Adoretus* showed this type of infection to be fairly common. Although, Marchal (1986) reported the presence of two gregarine species occurring simultaneously within *P. smithi*, only one was observed in our studies. More precise means of quantifying level of fat within the larvae should be devised. Moreover, the squirting method of extracting loose sporonts from within the digestive tract does not take into consideration gregarine stages that cling to the epithelial lining of the gut, nor does it take into account potential oocysts retained within the anal pouch. Isolated cases were encountered where oocysts occurred in the anal pouch without any sporonts being detected in the foregut. This concurs with Vercambre's findings on *P. smithi* in 1990. In that sense, it is particularly important to be able to isolate the gregarine for identification purposes and for further studies.

Surany (1960), Vercambre and Robert (1985), Vercambre (1990) and Marchal (1986) were of opinion that an important bio-regulation had caused a gradual reduction in the destructive capacity of *P. smithi*. Mention is made of the impairment of normal feeding due to partial blocking of the alimentary canal, thereby limiting the larva's capacity to ingest cane roots (Marchal 1986). It has also been considered that gregarines could tap the fat body reserve necessary for reproduction (B. Vercambre, pers. comm.). The possibility of gregarine-infested larvae being predisposed to other soil-borne pathogens, e.g., to bacterial septicaemia that cause dark spots on the body cannot be ruled out.

ACKNOWLEDGEMENTS

We express our gratitude to Dr Bernard Vercambre former Entomologist at CIRAD - Réunion for fruitful discussion in the initial stages of this study, to the Deputy Director (Biology) and the Director of the MSIRI and to Dr J R Williams for valuable suggestions in the preparation of the manuscript. The help provided by sugar estates in providing field specimens and the Entomology staff is acknowledged.

REFERENCES

DE CHARMOY D D'E. 1912. *Report on Phytalus smithi (Arrow) and other beetles injurious to the sugarcane in Mauritius.* Govt. Printing Office, Port Louis 34 p.

GREATHEAD DJ. 1971. *A review of biological control in the Ethiopian Region*. Tech. Comm. No.5. Commonwealth Institute of Natural Control. 162 p.

MARCHAL M. 1986. Rapport de mission effectuee a Maurice juin 1986. INRA/La Miniere.

MAURITIUS SUGAR INDUSTRY RESEARCH INSTITUTE. 1982. *Ann. Rep. Maurit. Sug. Ind. Res. Inst*. 1981. p. 47-48.

MOUTIA LA and MAMET R. 1946. A review of twenty-five years of economic entomology in the island of Mauritius. *Bull. Ent. Res*. 86 (4) p. 439-472.

MSIRI *see under* Mauritius Sugar Industry Research Institute

POINAR GO JR and THOMAS GM. 1978. *Diagnostic Manual for the Identification of Insect Pathogens.* Plenum Press. p. 99-103.

SURANY P. 1960. *Diseases and biological control in Rhinoceros Beetles*. Tech. Paper no. 128. South Pacific Commission. p.53-54.

TANADA Y and KAYA HK. 1993. *Insect Pathology*. Academic Press. Inc. London. p. 414-423.

UNDEEN AH and VAVRA J. 1997. Research Methods for entomopathogenic Protozoa. p 117 - 151. In Lacey L ed. *Manual of techniques in insect pathology*. Biological Techniques Series. Academic Press. London.

VERCAMBRE B and ROBERT PH. 1985. Rapport de la mission effectuee a L'ile Maurice. Mai-juin 1985. Laboratoire D' entomologie. CIRAD/IRAT- Reunion.

VERCAMBRE B. 1990. Compte- Rendu de mission concernant la gregarine de *Clemora smithi*. Laboratoire d' entomologie . CIRAD/IRAT- Reunion.

CONTROL OF *Plutella xylostella* AND *Crocidolomia binotalis* THROUGH THE COMBINED EFFECTS OF *Bacillus thuringiensis* AND BOTANICAL PESTICIDES

S Facknath

University of Mauritius

ABSTRACT

Spraying of a commercial formulation of Bacillus thuringiensis and an easy-to-prepare aqueous leaf extract of 1 of 3 botanicals, namely neem (Azadirachta indica), ayapana (Ayapana triplinervis) and vieille fille (Lantana camara), on alternate weeks showed good pest control properties, against the Lepidopteran pests Plutella xylostella and Crocidolomia binotalis, in field cabbages. The treatments were found to be as effective as the recommended synthetic organophosphate insecticide, Tokuthion. The botanicals had an enhancing influence on the Bt, the combination treatments being more efficient than the individual botanical or Bt treatments alone. Such an integrated approach has important implication in the environmentally- safe control of pests

Keywords: *Plutella xylostella, Crocidolomia binotalis, Bacillus thuringiensis***,** control, botanical pesticides, neem, *Azadirachta indica, ayapana, Ayapana triplinervis, Lantana camara*

INTRODUCTION

Studies on environmentally safer measures of pest control have been ongoing in Mauritius for a long time now. Biological control has been the dominant approach for the control of all the important sugarcane pests, and several of the horticultural pests. Non-chemical methods studied include mechanical movement (of grain), for the control of stored grain pests, intercropping, and various combination treatments (Facknath and Lalljee 1999a). Biology-based methods such as the use of Insect Growth Regulators, semiochemicals, allelochemicals have also been investigated to varying extents. A large number of allelochemicals have been screened and studied in Mauritius against a range of pests for pest control potential (Facknath 1998; Facknath and Lalljee 1999b, 1999c).

Bacillus thuringiensis (Bt) is a bacterium naturally occurring in soils worldwide. Its insect control potential was recognised ion the early nineties and the first commercial product was made in 1938. Bt has been extensively studied through out the world and is now widely accepted for pest control. The spores and crystal proteins (called delta-endotoxins) cause gut paralysis in certain insect orders, resulting in inability to feed, starvation and death. Other effects include interference in RNA transcription, disturbance in ATP production and disequilibrium in membrane permeability. Sublethal doses lead to prolonged development, deformities of the body and infertility.

Studies on Bt in Mauritius started way back in 1976 (Ramgoolam 1976). Over the next 20 years, a few investigations were made, sporadically, in order to test Bt formulations appearing on the world market, for instance Dipel was tested by the Ministry of Agriculture in 1984 and Cutlass in 1994. The University of Mauritius tested Turex in 1993 and 1995, and Condor in 1994. At present AGREE, an aizawai subspecies, is being tested at the University and the MSIRI. However, in spite of the promising results obtained in the majority of these experiments, Bt has not been commercialised in Mauritius. One probable reason for this may be the fact the Bt acts only against certain pest groups, namely Lepidoptera, Coleoptera and Diptera. The other insect pests would still require the use of chemicals. Another strong reason may be the possibility of overuse or misuse by farmers, as is the case with chemical pesticides, and which will result in the rapid development of resistance in the targeted pests. In fact, resistance to Bt has already been recorded in the case of *Plutella xylostella* in some countries (Tabashnik et al 1990; Van Rie et al 1990; MacIntosh et al 1991).

While the situation regarding farmers' perception and use of pesticides in Mauritius fully justifies the hesitancy exhibited so far with respect to the recommendation of Bt as the sole control measure, use of Bt can be, and should be, advocated within an Integrated Programme of Pest Management.

In this study, the combined influence of Bt with a botanical pesticide (either neem (*Azadiracta indica*), ayapana (*Ayapana triplinervis*) or vieille fille (*Lantana camara*)) was studied for the control of some cruciferous pests, namely *Plutella xylostella* and *Crocidolomia binotalis*. The pest control potential of neem, *Ayapana* and *Lantana* has already been demonstrated by Facknath (1994) and Lalljee and Facknath (1997), while Goolaub (1995) recorded the *Plutella* controlling effect of Bt.

A combined approach would, on one hand, reduce the amount of the Bt formulation needed (thereby reducing costs, risk to non-target organisms, and the risks of resistance), and on the other, significantly decrease farmer dependence on synthetic pesticides. In the larger context, this would translate into reduced pesticide contamination of the environment.

MATERIALS AND METHODS

Preparation of Extracts

One part of neem (*Azadirachta indica*) leaves were crushed in an electric blender with 3 parts of water.

The mixture was left overnight on a shaker for maximum extraction and then filtered through a muslin cloth. The filtrate was diluted with water to 10% and a few drops of Teepol added as a sticker.

Ayapana leaf extract and *Lantana* leaf extract were similarly prepared.

The extracts were prepared fresh every week prior to application.

Treatment Application

Nine subplots of 3.5 x 4.0m each were planted with cabbage seedlings on the University farm, and treated, in a randomised block design, with 1 of the following treatments, replicated thrice:

T_1	untreated control
T_2	sprayed weekly with 1.5 ml/l Tokuthion (prothiofos)
T_3	sprayed weekly with 10 % aqueous neem leaf extract
T_4	sprayed weekly with 10 % aqueous Ayapana leaf extract
T_5	sprayed weekly with 10 % aqueous Lantana leaf extract
T_6	sprayed weekly with 1 g/l Bt formulation
T_7	sprayed weekly with 1 g/l Bt formulation + 10% neem leaf extract
T_8	sprayed weekly with 1 g/l Bt formulation + 10% Ayapana leaf extract
T_9	sprayed weekly with 1 g/l Bt formulation + 10% Lantana leaf extract

All treatments were started as from the 3rd week of transplantation and stopped 2 weeks prior to harvest.

Irrigation and fertiliser applications were carried out as per the recommendations. Weeding was done manually.

OBSERVATIONS

The following parameters were noted :

Larval counts at 4, 7 and 10 weeks after plantation, 1 day prior to the spray treatments.

The number of *Plutella* larvae and pupae, and *Crocidolomia* larvae on 15 plants chosen randomly from each subplot.

The total number of cabbage plants in each subplot with at least 1 *Plutella* or *Crocidolomia* larva (i.e. the total number of infested plants/subplot).

Quality of harvested cabbages, in terms of insect infestation.

Total yield in terms of number of cabbage heads harvested /treatment and weight of marketable heads in kg.

RESULTS AND DISCUSSION

Tables 1 and **2** show the number of *Plutella xylostella* larvae and pupae and *Crocidolomia binotalis* larvae recorded at 3 times during the crop cycle. The untreated plots showed more than a doubling of the *Plutella* population over the first 3 week period and more than 3 times the population over the next 3 week period (**Table 1**). In the neem, *Ayapana* and *Lantana* treatments, the increase in *Plutella* populations was much less pronounced, with significantly smaller populations at 4 weeks after planting (WAP). Interestingly, *Plutella* numbers at 4WAP in the Bt plot were similar to that in the untreated plots, but did not show the same substantial increase over time, being almost a quarter of the unchecked *Plutella* population at 10 WAP.

Table 1 Number of *Plutella* larvae and pupae / 15 plants / plot

Treatment	4 WAP	7 WAP	10 WAP
T_1	51.7 ± 3.5 a *	117.3 ± 7.3 a	193.3 ± 8.5 a
T_2	10.0 ± 2.7 e	14.7 ± 2.9 d	18.7 ± 4.2 c
T_3	37.3 ± 4.3 c	40.7 ± 3.7 c	51.0 ± 5.3 b
T_4	41.7 ± 4.4 bc	50.0 ± 4.4 b	56.3 ± 6.7 b
T_5	45.0 ± 3.6 b	49.3 ± 6.3 b	50.7 ± 7.1 b
T_6	50.7 ± 6.3 a	56.7 ± 7.1 b	58.7 ± 7.3 b
T_7	10.3 ± 2.7 e	16.0 ± 3.4 d	19.3 ± 3.4 c
T_8	13.0 ± 3.1 d	19.7 ± 4.5 d	20.7 ± 3.6 c
T_9	12.7 ± 3.3 d	19.3 ± 4.9 d	20.3 ± 4.9 c

* Means ± s.e. Values followed by the same figure down a column are not significantly different.

The combination treatments of Bt with a botanical were significantly more effective in reducing the rate of increase in *Plutella* population.

Similar results were noted for *Crocidolomia* larvae, where the neem + Bt combination was significantly superior to the other 2 combination treatments. In fact, in case of *Crocidolomia*, the combination of Bt and a botanical was observed to be more effective than even the Tokuthion treatment, whereas they were comparable in case of *Plutella xylostella*.

Table 2 Number of *Crocidolomia* larvae / 15 plants / plot

Treatment	4 WAP	7 WAP	10 WAP
T_1	10.3 ± 4.1 a *	24.0 ± 8.8 a	33.7 ± 9.6 a
T_2	6.3 ± 4.8 c	7.3 ± 4.5 c	10.7 ± 4.4 c
T_3	8.0 ± 3.1 b	11.7 ± 4.0 b	14.0 ± 5.0 bc
T_4	8.3 ± 3.6 b	12.3 ± 3.4 b	15.7 ± 4.9 b
T_5	9.0 ± 4.2 ab	12.0 ± 3.7 b	17.0 ± 5.3 b
T_6	12.0 ± 5.0 a	13.3 ± 2.9 b	14.7 ± 5.0 b
T_7	1.7 ± 0.8 e	3.0 ± 0.9 e	3.7 ± 1.1 e
T_8	3.3 ± 1.9 de	5.7 ± 1.6 d	6.7 ± 2.0 de
T_9	4.7 ± 1.8 d	7.0 ± 2.5 c	8.3 ± 3.3 d

* Means ± s.e. Values followed by the same figure down a column are not significantly different.

The progression of infestation followed a similar pattern, with 98.3% of the cabbages being infested at 9 WAP by either *Plutella* or *Crocidolomia* or both, as compared to only 23.3% in the neem + Bt treatment (**Table 3**). The synthetic pesticide protected the plants by almost 90%, while Bt alone gave 50% protection. The *Ayapana* and Lantana combination treatments were intermediate in their efficacy.

Table 3 Number of infested cabbage plants / plot

Treatment	6 WAP %	9 WAP %
T_1	67.5	98.3
T_2	6.8	10.8
T_3	32.5	37.5
T_4	46.8	58.3
T_5	31.8	49.3
T_6	40.8	50.0
T_7	11.8	23.3
T_8	30.8	41.8
T_9	25.0	35.0

The quantity and quality of harvested cabbage heads (**Table 4**) were in keeping with above results.

Table 4 Yield and quality of harvested cabbage heads / plot

Treatment	Grade A *%*	Grade B *%*	Grade C *%*	Total Wt. *kg*
T_1	0	20.7	79.7	10.6
T_2	70.3	25.6	4.6	70.4
T_3	39.8	40.1	20.0	58.3
T_4	20.4	34.7	44.8	37.4
T_5	35.2	35.5	29.3	47.6
T_6	51.6	25.7	22.7	55.1
T_7	75.9	19.2	4.9	68.4
T_8	63.5	20.1	16.8	60.1
T_9	72.7	18.3	9.0	65.5

Neem +Bt was observed to be as good and as effective as the Tokuthion treatment, both in terms of the quality and quantity (in terms of marketable heads / plot) of the yield.

Neem alone increased the number and weight of marketable heads as compared to control, and so did Bt alone. It is noteworthy that Bt produced a greater numb er of Grade A cabbages than did neem alone. A possible explanation may be that the Bt crystal protein paralyses the insect gut, and prevents further feeding, while the antifeedance of neem may be overcome to some extent by extreme hunger. The number of Grade A cabbages was highest in the neem +Bt treatment, being slightly higher than even the Tokuthion treatment.

The Bt crystal protein acts by preventing feeding by the caterpillars, and in this case, is effective a few days after ingestion by the insect. Death of the insect may take up to a week, depending upon the age and size of the larvae as well as upon the amount consumed. Neem, Ayapana and *Lantana*, on the other hand, act as antifeedants, making the food unpalatable to the insect.

Mixing the spray liquids (for e.g. Bt and botanical) has been shown to be highly variable in it effects, being antagonistic in some cases and synergistic in others. Chiu Shin-Foon (1990) demonstrated the efficacy of Bt with ethanol extracts of *Derris* roots on *Crocidolomia binotalis*, while Ramaprasad et al (1982) recorded the efficiency of Bt with aqueous extracts of *Pongamia glabra* on *Spodoptera litura*. While neem enhanced the action of Bt against *S. frugiperda* (Hellpap and Zebitz 1986), Moar and Trumble (1987) reported an antagonistic effect of neem on Bt against *S. exigua*. An explanation of this apparently paradoxical difference may be that in some cases the antifeedant property of the botanical inhibits feeding and may therefore prevent the insect from acquiring a dose of Bt sufficient to cause paralysis of the gut cells. In other situations, if the insect has already ingested a sufficient concentration of the Bt protein, then the inability to feed may be further strengthened by the antifeedance of the botanical. Hence in the present study, all the combination treatments were started with Bt. Furthermore, the younger larval instars are more susceptible to Bt than are the older ones, and are killed at concentrations lower than those required to kill the older larvae.

Bt has also been evaluated for its joint action with other natural enemies among them the Nuclear Polyhedrosis Viruses which are pathogenic in *Heliothis virescens*, as well as parasitoids, such as *Diadegma eucerophaga* and *Cotesia plutellae*. It was observed that the 2 hymenopteran parasitoids, in combination with Bt, were effective in controlling *Plutella* without having recourse to chemical insecticides. Neem and *Ayapana* are well known in their effects on mammal, including humans. They have been shown to be harmless on contact as well as on ingestion. In fact, in some countries, neem leaves are cooked and eaten as a vegetable, while the tender twigs are chewed as a means of dental hygiene. Concoctions of *Ayapana* leaves are also recommended for certain gastric disorders.

Bt is also environment-friendly, being rapidly degraded by sunlight, UV and high temperatures within a few days. Although the spores can remain dormant and in a viable state in soil for several months, they are not taken up by plants, and must be eaten by a susceptible insect in order to germinate and release the toxic protein. Some Bt formulations have a recommended frequency of application of 14 days. With such formulations the botanical spray may be applied 2 weeks after the Bt spray. And then a week following the botanical spray, the Bt treatment may be reapplied.

With the released natural enemies of *Plutella xylostella*, botanicals and Bt can together constitute an effective and environmentally safe IPM programme. Coupled with farmer education and strong extension activities, such a combination approach can definitely help reduce pesticide use in our country.

REFERENCES

CHIU SHIN-FOON. 1990: Investigations on botanical insecticides in South China-an update.p. 134-137 *In* : *Proc. Symp. Bot. Pesticides in IPM, Rajahmundry*..

FACKNATH S and LALLJEE B. 1999a: A novel, environmentally-friendly strategy using neem and grain tumbling for the control of stored product insect pests. *Phytoparasitica* [In Press].

FACKNATH S and LALLJEE B. 1999b. Response of three important insect pests of horticultural crops in Mauritius to extracts of *Ayapana triplinervis*. *Journal of Applied Entomology* [In Press].

FACKNATH S and LALLJEE B. 1999c. Status of Allelopathy Research in Mauritius. *In* : *Allelopathy Update*. Vol 1 : International Status. Oxford and IBH Publishing Co. Pvt. Ltd. 271-293.

FACKNATH S. 1994. "Green" Pesticides for the control of some important pests in Mauritius. *Pesticide Outlook*. Vol. 5(2). 24-27.

FACKNATH S. 1998. Application of neem extract and intercropping for the control of cabbage pests in Mauritius. *In* : R.P.Singh abnd R.C. Saxena Eds. Azadiracta indica A. Juss.. *Proc. International Neem Conference, Queensland, Australia, February 1996* . Oxford and IBH Publishing Co. Pvt. Ltd. - 165-175.

GOOLAUB A. 1995. Study of a *Bacillus thuringiensis* formulation for the control of some important Lepidopteran pests of agriculture. BSc. Project. Faculty of Agriculture, University of Mauritius.

HELLPAP C and ZEBITZ CPW. 1986. Combined application of neem seed extracts with *Bacillus thuringiensis* products in the control of *Spodoptera frugiperda* and *Aedes togoi*. *J. Appl. Ent*. 101. 515-524.

LALLJEE B and FACKNATH S. 1997. Biocidal potential of *Eupatorium ayapana* extracts. *Book of Abstracts. Symposium on Integrated Pest Management for Sustainable Crop Production, 2-4 Dec. 1997,* IARI, New Delhi, India. 64.

MACINTOSH SC; STONE TB, JOKERST RS, FUCHS RL. 1991. Binding of *Bacillus thuringiensis* proteins to a laboratory selected strain of *Heliothis virescens*. *Proc. Nat. Aca. Sc*. USA 88. 8930-8933.

MOAR WJ and TRUMBLE JT. 1987. Toxicity, joint action and mean time of mortality of Dipel, avermectin, neem and Thuringiensin against beet armyworms (Lepidoptera : Noctuidae). *J. Econ. Ent*. 80. 588-592.

RAMAPRASAD G; JOSHI BG, SATYANARAYANA VV. 1982. Efficacy of some insecticides and *Bacillus thuringiensis* Berliner in the control of *Spodoptera litura* F. *Tob. Res*. 8(1). 13-18.

RAMGOOLAM. 1976. A preliminary investigation to assess the potential of *Bacillus thuringiensis* for the control of *Crocidolomia binotalis* Zell. B.Sc. project. School of Agriculture, University of Mauritius.

TABASHNIK BE, CUSHING NL, FINSON N, JOHNSON MW. 1990. Field development of resistance to *Bacillus thuringiensis* in Diamondback moth (Lepidoptera : Plutellidae). *Ec. Ent*. 83. 1671-1676.

VAN RIE J, MCGAUGHEY WH, JOHNSON DE, BARNETT BD, VAN MAELLARD H. 1990. Mechanism of insect resistance to microbial insecticide, *Bacillus thuringiensis*. *Science* 247. 72-74.

YELLOW STICKY TRAPS AS A MONITORING TOOL FOR EFFECTIVE CONTROL OF LEAF MINERS IN ONION

L Unmole, D Abeeluck* and *R Seetohul

Agricultural Research and Extension Unit

ABSTRACT

The efficacy of yellow sticky traps to monitor adult Liriomyza population was evaluated in onion fields at La Chaumiere. The traps were effective in monitoring adult population and as an additional tool to capture adult flies as well.

Pest profile studies were conducted at La Chaumiere and Reduit Research Station to study the development of mine formation on plants during the crop cycle. In both sites, an average of 2 mines per plant was observed at 32 days after transplantation. Thereafter, the number of mines increased sharply up to 7.8 mines/plant at bulb formation.

Trap captures (400/trap/week) and the number of mines per plant (2mines/plant) are strongly related and could be used as indicators to time insecticide applications in onion fields. When the threshold value (400/trap/week or 2 mines/plant) is reached, an adulticide could be applied as a first treatment and a larvicide after 7 days. Treatments based on these indicators could reduce the prophylactic spraying and increase the efficiency of insecticide use.

Keywords : *Liriomyza* spp., onions, pests, yellow sticky traps, threshold value, control

INTRODUCTION

Leaf miners, *Liriomyza trifolii* Burgess and *L. huidobrensis* Blanchard are polyphagous insect pests. In Mauritius, *L. trifolii* has been recorded on 24 different host plants and *L. huidobrensis* on 18 (Rajabalee 1993). Tomato, potato, pulses and onion are some of the major crops susceptible to *Liriomyza* attacks. Both adults and their larvae cause damage to leaves. The feeding and oviposition punctures made by adult females on leaves are points of entry for fungi and bacteria and the mining activity of larvae reduces the photosynthetic capacity of plants. Heavy infestation leads to drying of leaves and young plants may be completely destroyed.

From 1980 to 1984, insecticides (e.g., organophosphates, pyrethroids) were the only means to control *Liriomyza* spp. (Rajabalee et al. 1992). Resistance of *L.trifolii* to a number of compounds has been reported by Parella et al.(1984). In Mauritius, Serret (1986) reported resistance of *L. trifolii* to a number of pyrethroids and organophosphates. As from 1985, an Integrated Pest Management Programme was initiated and which included components, such as biological control and use of growth regulators (Rajabalee et al. 1992; Rajabalee 1993).

In 1995, yellow sticky traps, mounted on tractors during spraying operations in a potato field were used to capture adult flies (Anon 1996). Yellow sticky cards were first used to sample adult leafminers in the genus *Liriomyza* (Mk) by Musgrave et al. (1975) and Tryon et al. (1980) confirmed that yellow was more attractive to adults than other colours. Parrella et al. (1985) developed a sequential sampling plan using yellow sticky traps to monitor adult *L. trifolii* populations in chrysanthemum greenhouses.

The present study was undertaken to determine the efficacy of yellow sticky traps as a tool to monitor adult *Liriomyza* population in onion plantation and the critical stage to initiate control actions.

MATERIALS AND METHODS

Description of trap

The trap consisted of a 4 mm plywood board (30 cm x 45 cm in size) and a wooden frame. The board was painted on both sides with lemon yellow (oil emulsion paint), sealed in a transparent plastic cover and smeared with an adhesive (automobile grease). The wooden frame held the sticky board in a horizontal position just above the crop and could be adjusted whenever the crop attained additional growth.

Trapping trials

Trapping studies were carried out in homogeneous blocks of onion fields under farmers' control practices at La Chaumiere.

Two plots, each of 10 m x 17 m in size and at 100 m from one another, were selected. Seedlings of Yellow Dessex variety were transplanted in the two plots on the same date. Farmers treated the crop with Cymbush 10 EC and Fenitrothion 4 EC alternately at 15 days interval. Three sticky traps (spaced at 10 m apart) were placed in each plot.

All trapping at La Chaumiere was initiated on 11 June (13 days before transplantation). The yellow sticky boards were removed from plots every 7 days and replaced by new ones. Captured flies were counted, identified and sexed. This study was run for 12 weeks until harvest. From each plot, 12 plants were randomly selected and tagged. The number of mines on tagged plants was recorded every 14 days.

Pest profile study

Studies on the development of mine formation on plants during the crop cycle were undertaken in insecticide-free plots of onion at Reduit Research Station from June 1998 to August 1998 to determine the time at which control actions could be initiated.

Three plots (each of 8 m 25 x 7 m in size) with five beds (each of 1 m x 5 m x 10 cm in size) were set up. Each bed contained 300 onion seedlings of Yellow Dessex variety, planted at a distance interval of 10 cm. Standard cultural practices (fertilization, weeding and disease control) were used to maintain the plants but without insecticide application.

From each plot, 20 plants were randomly selected and tagged. The number of mines on leaves (upper and lower part) was recorded every 7 days (1/06/98 to 29/06/98) and every 15 days (29/06/98 to 24/08/98).

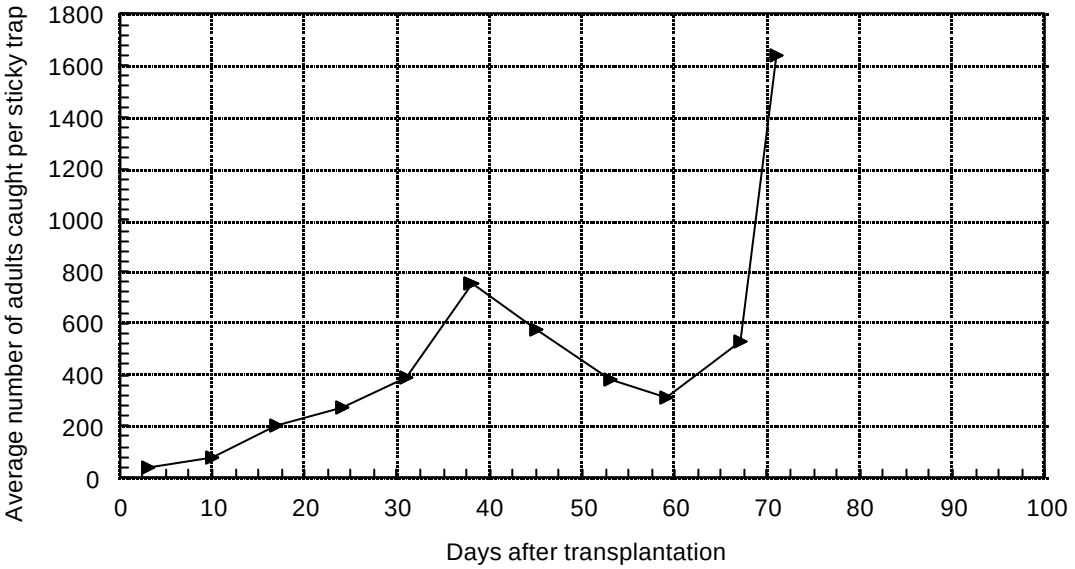
RESULTS AND DISCUSSION

Trapping at La Chaumiere

The average number of flies per trap per week was 431. Both adults of *L. trifolii* and *L. huidobrensis* were captured; the former being most abundant (98 %) with a male bias sex ratio (3:1). Before transplantation, the average number of flies/trap/week was 5.5.

As from three days after transplantation date (DAT), the average number of flies per trap per week increased to a peak of 754 flies at 38 DAT (at 8 leaf-stage). Captures then dropped to a minimum of 300 at 59 DAT. Thereafter, captures reached a maximum of 1650 flies/trap/week at 71 DAT (**Figure 1**).

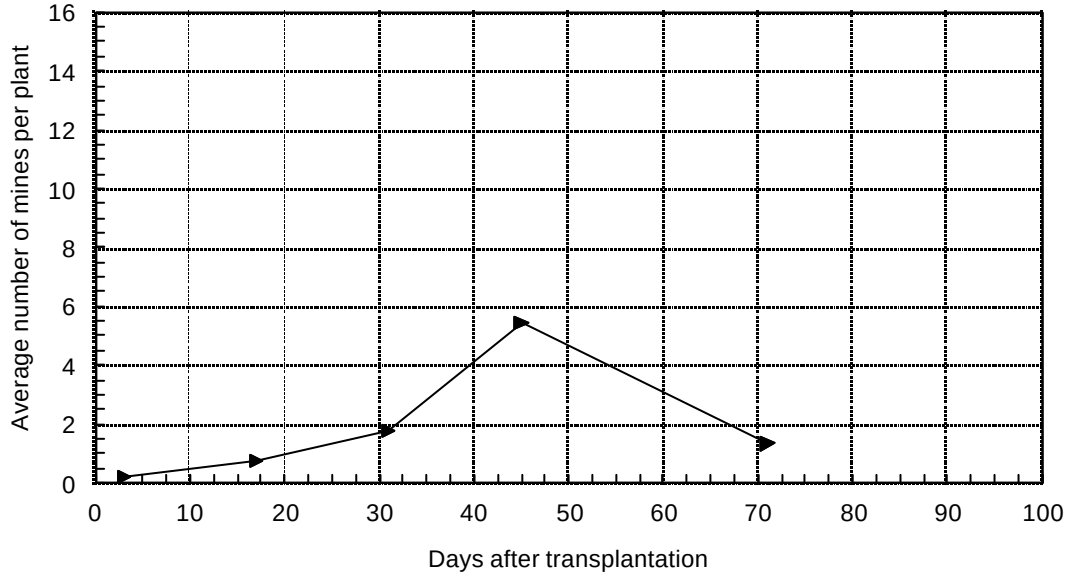
Figure 1 Average number of adult flies per sticky trap at La Chaumière from June to September 1998



Assessment of the number of mines on plants in plots with yellow sticky traps at La Chaumiere

The average numbers of mines per plant, at 3 DAT (3 leaf-stage) and at 31 DAT (7 leaf-stage) were 0.2 and 2.0 respectively. As from 31 DAT, the number of mines per plant rose to a maximum of 5.5 at 45 DAT (**Figure 2**).

Figure 2 Average number of mines per onion plant at La Chaumière from June to September1998

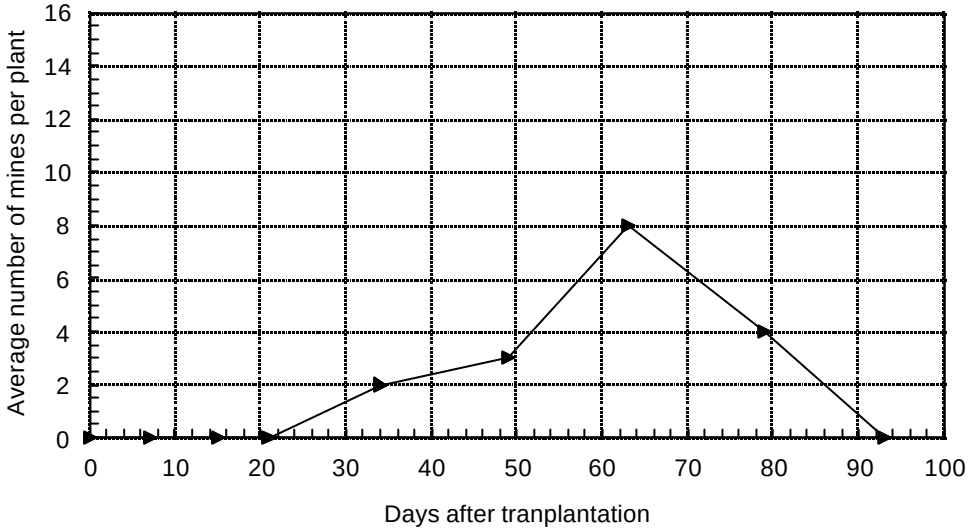


Determination of critical stage when control measures need to be initiated at Reduit

The average number of mines per plant in insecticide-free plots was 0.05 mines/plant up to 3 leaf-stage on the date of transplantation. At 35 DAT (7 leaf-stage), an average of 2.0 mines per plant was

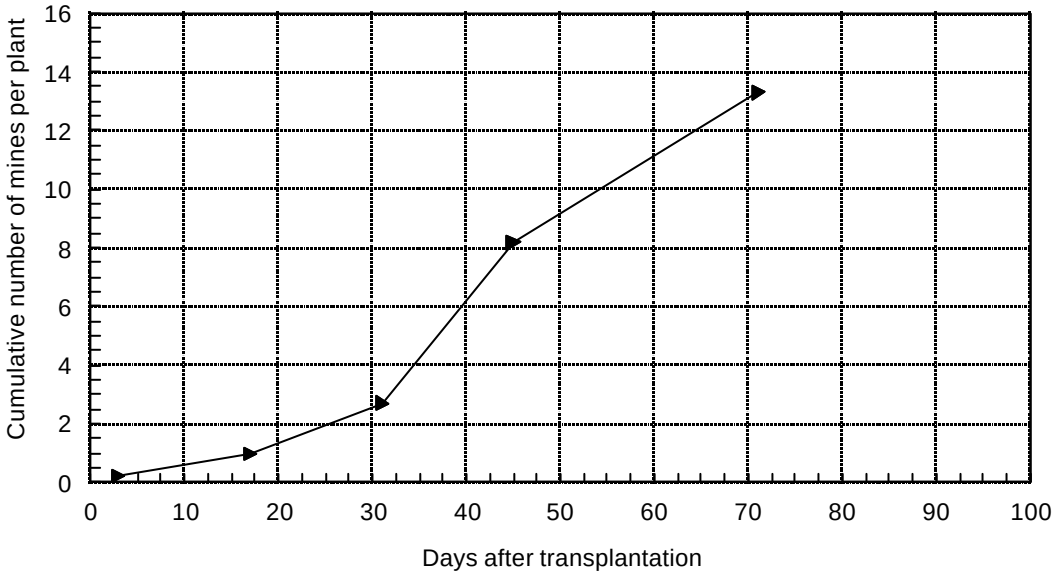
recorded and subsequently increased to a maximum of 7.8 mines/plant at 63 DAT. As from 63 DAT to 93 DAT, the number of mines dropped to 0.2 (**Figure 3**).

Figure 3 The average number of mines per onion plant at Réduit station from May to August 1998



90% of the mines were concentrated on the upper part of leaves. During the crop cycle, the cumulative number of mines per plant at La Chaumiere and at Reduit were 13.3 and 13.6 respectively (**Figures. 4** and **5**).

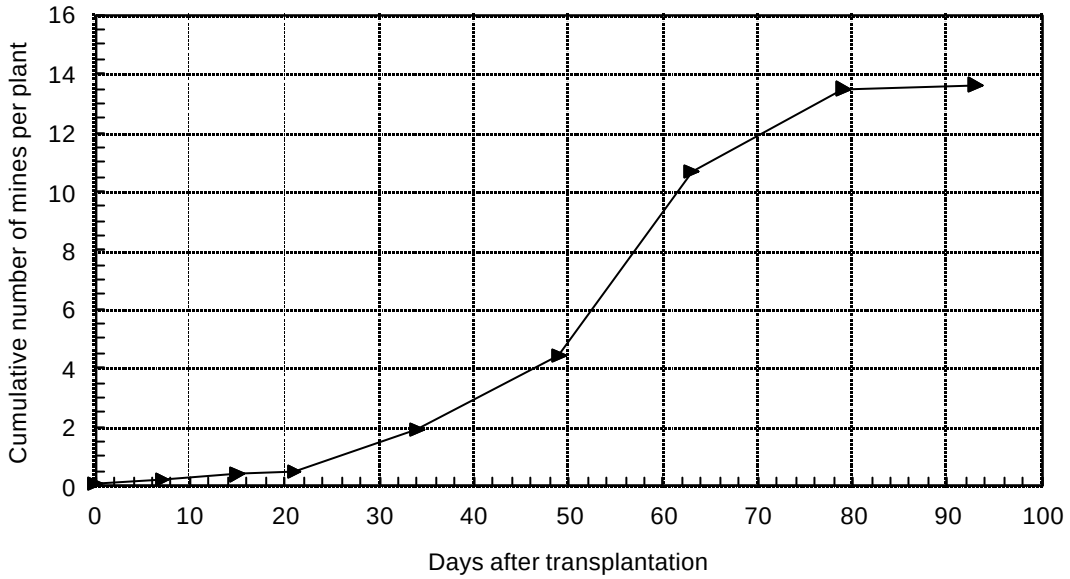
Figure 4 Cumulative number of mines per onion plant at La Chaumière from June to August 1998



The trap captures could be characterised into 3 phases: a first phase with an increase in captures up to 38 DAT (8 leaf-stage), a second with a decline in numbers as from 38 DAT to 59 DAT (8 leaf-stage to 12 leaf-stage) and a third with a rapid increase as from 71 DAT (13 leaf-stage) to harvest time (**Figure. 1**). The increase in captures at 71 DAT (at harvest period) could be an effect of immigrating flies from adjoining fields because the larval population in the experimental plot was low (**Figure. 2**). The yellow traps were more attractive than the plants that were in senescence stage (with drying leaves) because the lemon yellow colour acts as a mimick of foliage (Prokopy 1972). Trap captures are strongly related

to the number of mines per plant. High captures resulted in high numbers of mines after 7 days (**Figures. 1** and **2**). This indicated that during periods of high captures, egg deposition on leaves was highest. Eggs normally hatch after 2 to 3 days (Parella 1987) and this could explain the high numbers of mines 7 days after the date when high numbers of adults were captured.

Figure 5 : Cumulative number of mines per onion plant at Réduit Station from May to August 1998



Mine formation in the experimental plot could be characterised into 2 phases. The first phase showed a rapid increase in the numbers of mines right from 3 DAT (3 leaf-stage) to 45 DAT (9 leaf-stage) and the second one with a decline after 45 DAT (9 leaf-stage).

At Reduit Research Station, there had been a similar trend in mine formation in onion plots but with 3 phases. The first phase showed a low incidence of mines up to 21 DAT (6 leaf-stage), a rapid increase in the second (up to 13 leaf-stage) and a sharp decline till the end of the crop cycle in the third one (**Figure 3**).

The first phase could be an initial colonisation period by immigrating flies from adjoining fields. The availability of new leaves during the second phase permitted an increase in the numbers of mines on plants. The third phase coincided with bulb formation period with a decline in the numbers of mines. During this phase, the plants were not attractive to ovipositing females because they had fewer new leaves with low leaf areas and most of the photosynthates of leaves were probably diverted towards bulb formation.

Mine formation on leaves started from 21 DAT (6 leaf-stage) at Reduit and from 3 DAT (3 leaf-stage) at La Chaumiere. The number of mines at La Chaumiere from the 3 to 6 leaf-stage were four times higher than that at Reduit because there had been a comparatively higher adult population at the transplantation date at La Chaumiere. In both sites, an average of 2 mines per plant was observed at 32 days after transplantation. In both sites, an average of 2 mines per plant was observed at 32 - 35 days after transplantation. Thereafter, the number of mines increased sharply up to 7.8 mines/plant at bulb formation. Therefore, 2 mines/plant was the critical point when control action was warranted. The threshold of 2 mines/plant (32 DAT) corresponded to a capture of 400 adult flies per trap (**Figure. 1**).

CONCLUSION

The captures of adult flies on the yellow sticky trap (400 adult/trap) and an average number of 2 mines/plant can be used as indicators to time insecticide application in an onion crop cycle. When the threshold of 400 adult flies per trap or 2 mines/plant is reached, an adulticide could be used as a first

treatment and subsequently a larvicide after 7 days. Treatments based on these indicators could reduce prophylactic spraying and increase the efficiency of insecticide use. Besides the sticky traps also functioned as a physical method to capture adult flies and could also be used as an additional component in an Integrated Pest Management Programme against *Liriomyza spp* in onion plantation.

ACKNOWLEDGEMENTS

We extend our gratitude to the onion growers of La Chaumiere, personnel of the Reduit Research Station and the staff of the Entomology Division of AREU for their assistance during research. The statistical advice of Mr R Ramnauth of the Biometry section is gratefully acknowledged.

REFERENCES

ANON. 1996. *Annual Rep. Maur. Sug. Ind. Res. Ins.* 1995

MUSGRAVE CA, POE SL and BENNETT DR. 1975. Leafminer population estimation in polycultured vegetables. *Proc. Fla. State. Hortic. Soc*. 88: 156-160

PARELLA MP and KEIL CB. 1985. Insect Pest Management: The lesson of *Liriomyza*. *Bulletin of the ESA* 30: 22-25

PARELLA MP, KEIL CB and MORSE JG. 1984. Insecticide resistance in *Liriomyza trifolii*. *Calif. Agric*. 38: 22-23

PARELLA MP. 1987. Biology of *Liriomyza*. *The Annual Review of Entomology* 32, 201-224

PROKOPY RJ. 1972. Response of apple maggot flies to rectangles of different colours and shades. *Environ. Entomol*. 720-6

RAJABALEE A, GANESHAN S and BANYMANDUB N. 1992. La lutte integrée pour la controle des chenilles mineuses sur la pomme de terre à Maurice. *Revue Agricole et Sucrière*. Vo. 2 and 3 Vol. 73 p 143- 147.

RAJABALEE A. 1993. Les chenilles mineuse du genre *Liriomyza* (Diptera: Agromyzidae) à Maurice. Colloque sur les mouche mineuse des plantes cultivées.

SERRET N. 1986. *Investigation of insecticide resistance in the leafminer Liriomyza trifolii*. Burgess (Diptera; agromyzidae). University of Mauritius, School of Agric.

TRYON EH JR., POE SL and CROMROY HL. 1980. Dispersal of vegetable leafminer onto transplant production range. *Fla. Entomol*. 63: 292-296

PEST RISK ANALYSIS AND QUARANTINE OF FRUIT FLIES IN THE INDIAN OCEAN REGION.

A Joomaye **and** *NS Price*

Indian Ocean Regional Fruit Fly Programme

Ministry of Agriculture, Food Technology and Natural Resources

ABSTRACT

The principles and procedures behind Pest Risk Analysis (PRA) are demonstrated by their application to economically important fruit fly pest species recorded within the Indian Ocean Region. The greatest quarantine risk to individual countries by such species is by their movement and introduction in infested fruit carried by air travellers and the potential significance of quarantine failure is demonstrated. Further consideration is given to the threat posed by fruit fly species occurring outside the Indian Ocean region.

Keywords : fruit flies, pest risk analysis, quarantine, Indian Ocean

INTRODUCTION

Risk exists 'when the number of possible future events exceeds the number that will actually occur and some measure of probability can be attached to them' (Bannock et al. 1992). No human activity, especially agriculture, can claim to be risk-free and the concept of zero risk is untenable.

"Pest Risk Analysis" (PRA) is the application of sound scientific principles to identify, evaluate and manage pest risks associated with trade and travel and is intimately associated with quarantine regulations that may hinder free trade and movement. PRA examines whether the criteria for the quarantine pest status of an animal or disease are justified. PRA examines the whole sequence of events that pests must survive if they are to become established in a new area and makes explicit and open the scientific judgements used. Such procedures are increasingly important as measure to liberalise world trade increase in importance. Agreement reached by signatories to the World Trade Organisation requires that "phytosanitary measure(s) are based on scientific principles and (are) not maintained without sufficient scientific evidence" (WTO 1999).

A sound, rational and internationally justifiable and defendable quarantine policy must be based on pest risk analysis. PRA relies on a full understanding of the biology, ecology, behaviour and control of the potential pest species under consideration and places considerable technical demands in the gathering and interpretation of the data needed to support accurate assessments. As any assessment may be limited by the amount of information available about each species PRA should be used cautiously and critically, its very openness to examination and criticism being crucial to ensuring that assessments are soundly based.

Applying Pest Risk Analysis to Fruit Fly Quarantine

Fruit flies (Diptera : Tephritidae) rank among the worlds most serious pests of horticultural crops. Besides causing direct losses in yield and marketability, they pose as significant threats to quarantine security and thus to international trade in fruits and fresh vegetables world-wide, including in the Indian Ocean Region. Fruit flies may gain entry to a region where they are not yet present by different pathways. Most important among these are as larval stages infesting fruit and vegetables either as imported fruit and vegetable products, via garbage, or in infested fruits in passenger luggage. The risk of introduction through imports is generally considered low mainly because imports of horticultural

produce are regulated by strict quarantine requirements. Garbage is of negligible risk if waste is properly disposed of under quarantine supervision. The illicit movement of fruits and vegetables coming from untreated areas and carried by sea and airline passenger presents the highest "risk pathway" for fruit fly introductions. Sea travel is considered so slow that infested fruit would generally have been consumed or discarded prior to arrival and therefore of these two airline traffic is considered by far the most important.

This paper will present an analysis of the risks associated with airline passengers carrying infested fruits into and within the Indian Ocean Region, by the process of PRA in accordance with Food and Agriculture Organisation Guidelines for Pest Risk Analysis (FAO 1995).

PEST RISK ANALYSIS

The FAO define a quarantine pest as "a pest of potential economic importance to (an) area and not yet present there, or present but not widely distributed and being officially controlled" (FAO 1999). Clearly a major component of justifying quarantine regulations against a pest is the demonstration of clear economic importance. For this to occur a pest must become established and spread in an area and it is the evaluation of the risks associated with this potential establishment and spread that form the core of PRA.

The main objectives of Fruit Fly PRA within the Indian Ocean Regional Fruit Fly Programme are to identify fruit flies of quarantine concern and to assess the risks associated with them. With this information the Programme assists countries of the region in preventing the introduction, establishment and spread of fruit flies of quarantine concern originating from within and outside the Indian Ocean Region.

IDENTIFICATION AND ASSESSMENT OF POTENTIAL QUARANTINE PESTS

A list of fruit flies together with their origin, distribution and their respective male attractants has been constructed for the major fruit fly species recorded within the Indian Ocean Region, drawn principally from distribution data published in White and Elson-Harris (1994) (**Table 1**). Male attractants (parapheromones) are widely used in traps to detect and monitor male fruit fly numbers. There are several male attractants available, (for example the Mauritius Trapping Network uses a total of five different attractants) and the often highly specific nature (to group or genus) of their attraction means that they can also be used as a diagnostic and taxonomic characteristic.

As all the fruit flies identified except Ceratitis capitata are absent from at least one country, all the species in **Table 1** (except *Ceratitis catoirii*, *Trirhithrum manganum* and *T.nigerrimum*) represent serious quarantine threats to one or more other countries of the Region and were thus subjected to PRA. This process was later extended to consider fruit flies present outside the Indian Ocean Region and the quarantine threat they presented. (This data is too extensive to permit full presentation here and will only be referred to in the Discussion).

PRA considers all aspects of the fruit fly, including biological and geographical distribution and its economic impact and importance. For its potential economic importance to be expressed, a fruit fly having entered must become established and spread in the endangered area. The basic information to estimate the establishment, spread and economic potential of the fruit fly within the endangered area will come from areas where the pest currently occurs. Among factors considered the extent of damage and the range of economically important fruits or vegetables attacked (monophagy, polyphagy) are most relevant. The final stage of assessment concerns the likelihood of entry, which depends on the pathway from the starting point to the destination. The "risk pathway" considered here is the illicit movement of fruits in airline passenger luggage.

For the assessment of the Risk of Introduction of fruit flies a clear logical sequence of five criteria has been followed in developing a scoring system. A single number is assigned to each point in the system, summing these over the whole sequence thus leads to a single value.

Table 1 Origin, Distribution and Male Lure attractant for economically important fruit fly species recorded in the Indian Ocean Region.

Fruit Fly Species	Region of Origin	Presence in the Indian Ocean Region (IOR)					Male Lure (3)
		Maur	Réu	Sey	Mad	Com	
Bactrocera cucurbitae (Coquillet)	Asia	+	+				CU
Bactrocera dorsalis (Hendel)	Asia	?(1)					ME
Bactrocera zonata (Saunders)	Asia	+	?				ME
Carpomya vesuviana Costa	Asia	+					None known
Ceratitis capitata (Weidemann)	Africa	+	+	+	+	?	TML, TA
Ceratitis pedestris (Bezzi)	Southern Africa and Madagascar				+		TML, TA
Ceratitis rosa Karch	Africa	+	+				TML, TA
Dacus bivittatus (Bigot)	Africa			2			CU
Neoceratitis cyanescens (Bezzi)	Madagascar	+	+		+		None known

(1) Declared eradicated in 1999; (2) A single individual in 1998; (3) ME = Methyl Eugenol, TML = Trimedlure, TA = Terpinyl Acetate; CU = Cuelure; VE = Vertlure.

Scores were assigned to the following five criteria:

Geographical and Regulatory Criteria, rated as either 1, 2, or 3 and determining whether or not fruit flies are present in the area considered. A score of 1 under Geographical and Regulatory Criteria means that the fruit fly is already present in the country under consideration and thus of no quarantine significance and is not considered further. Fruit flies scoring 2 or 3 will be quarantine pests and are considered further.

Economic Importance Criteria, categorised as:

a) 'Establishment Potential', particularly host range of the potential pest fruit fly species and the environmental suitability for the endangered area,

b) 'Dispersal Potential' which considers the suitability for the endangered area for the spread of the potential pest and the possible movement of the pest with fruit or vegetables within the endangered area. Due to the small size of the countries of the region (excluding Madagascar) it has been decided to exclude this criterion from the current exercise.

c) 'Economic Impact' considers the importance of any potential crop losses, possible loss of export markets, possible cost in control efforts etc. in the endangered area to the potential pest species

d) 'Environmental Impact' considers aspects such as the possible environmental effects of control measures in the endangered area that might be required should a potential pest species become introduced.

e) 'Introduction Potential' (pathway) considers the origin and frequency of air contacts between the endangered area and areas where the potential pest species is established.

The Economic Importance Criteria used (a, c, d and e) are each rated between 1 and 9. The sums of these four scores are then used to rate these potential pests as follows:

0 – 6	Marginal Risk;
7 – 10	Low Risk;
11 – 14	Moderate Risk;
15 and above	High Risk.

Using the above system, tables of Risk of Introduction have been constructed for each of the five countries of the Indian Ocean Region. (As an example the Risk of Introduction table for Mauritius is presented, **Table 2**). This in turn has enabled a summary table to be produced indicating the level of risk represented by each species recorded within the Indian Ocean Region to each country of the Indian Ocean Region (**Table 3**).

Table 2 Pest risk analysis of fruit fly species recorded in the Indian Ocean Region. Major risks of introduction to Mauritius by air passengers.

Fruit Fly Species	Introduction pathways	World distribution	GRC	Economic Importance Criteria					RR
				HR	ECI	ENI	IPP	TEI	
B. dorsalis	AM; AI	Oriental Asia	3	9	9	9	9	36	H
Ceratitis malgassa	AM; AMd	Madagascar	3	3	2	1	2	8	L
Cearatitis pedestris	AM; SAA; AZ	Africa, Madagascar	3	1	1	1	1	4	Ma
Dacus bivittatus	AM; SAA; AZ; BA	Africa	3	4	3	2	2	11	Mo
D. punctatifrons	AM; SAA; AZ; BA	Africa, Yemen	3	1	1	1	1	4	Ma
Dacus vertebratus	AM; SAA; A Md; AZ; BA	Africa, Madagascar, M. East	3	1	1	1	1	4	Ma

AM = Air Mauritius
AI = Air India
AMd = Air Madagascar
AZ = Air Zimbabwe
BA = British Airways
SAA = South African Airways

GRC = Geographical and Regulatory Criteria (1 - 3).

Economic Importance Criteria:

HR = Host Range / Establishment Potential
ECI = Economic Impact
ENI = Environmental Impact
IIP = Introduction Potential Pathways; (each 0 – 9)
TEI = Total Economic Importance (maximum possible = 36)

RR = Risk Rating

H = 15 + = High Risk
L = 7 – 10; = Low Risk
Ma = 0 – 6 = Marginal Risk
Mo = 11 – 14 = Moderate Risk

DISCUSSION

Risk Profiles of Major Fruit Flies Species recorded within the Indian Ocean Region

Bactrocera dorsalis remains the major threat to all countries of the region (**Table 3**). The detection of this species in Mauritius in June 1996 demonstrated its ability to gain entry and to establish in the region (Seewooruthun et al. 1998). Mauritius is more exposed to this menace than other sister islands due to the greater numbers of existing entry pathways, illustrated by the score of 9 under the "Introduction Potential: Pathway" criterion (**Table 2**). *B.dorsalis* is rightly considered as a major international quarantine pest. Other fruit fly species, namely *B.zonata*, and *B.cucurbitae* have been listed as "A1" quarantine pests by the Food and Agriculture Organisation and are major quarantine threats to Madagascar, Comoros and the Seychelles. Seychelles is considered more threatened than Madagascar and Comoros due to the existence of more varied and frequent entry pathways into the country.

Although *Ceratitis capitata* is the most widespread fruit fly pest species of the region quarantine measures may still be justified. Relaxing surveillance could lead to the introduction of new, possibly more injurious strains. *Ceratitis malgassa*, which occurs only in Madagascar, has not been able to establish outside its native range even though there has been regular traffic between Madagascar and its neighbours. It is rated as a Low Risk species.

The pest status of *Carpomya vesuviana* has not been accurately determined for the region however, it seems that it is present only in Mauritius. Although highly injurious to *Ziziphus* spp, it is considered as a Low Risk species within the Region except for Reunion where (due to its proximity to Mauritius) the species is rated as Moderate Risk.

D. bivitatus was recently detected in the Seychelles but according to trap surveys has not successfully established on the island. It is rated as a Moderate Risk species for all the countries of the region except Comoros where due to the infrequency of entry pathways it is rated as Low Risk. *Dacus ciliatus* is an exotic species present in Mauritius, Reunion and Madagascar. It has never been recorded in Seychelles and Comoros and is considered a Moderate Risk pest for these countries due to its serious pest status in Reunion and Mauritius.

Table 3 Risks of Introduction of Fruit Fly species recorded within the Indian Ocean Region from within the countries of the Indian Ocean Region.

<table>
<tr><th rowspan="2">Fruit Fly Species</th><th colspan="5">Country of the Indian Ocean Region</th></tr>
<tr><th>Mauritius</th><th>Reunion</th><th>Seychelles</th><th>Madagascar</th><th>Comoros</th></tr>
<tr><td>Bactrocera dorsalis (1)</td><td colspan="5">High risk</td></tr>
<tr><td>Bactrocera zonata</td><td rowspan="3">No quarantine risk</td><td colspan="4">High risk</td></tr>
<tr><td>Bactrocera cucurbitae</td><td rowspan="2">No quarantine risk</td><td colspan="3" rowspan="2">High risk</td></tr>
<tr><td>Ceratitis rosa</td></tr>
<tr><td>Ceratitis capitata</td><td colspan="5">No quarantine risk however introduction of new strains should be prevented</td></tr>
<tr><td>Ceratitis malagasa</td><td colspan="2">Low risk</td><td colspan="2">No quarantine risk</td><td>Low risk</td></tr>
</table>

(1) B.dorsalis is retained in this table although no longer considered present within the Indian Ocean Region following the declaration of its eradication from Mauritius in 1999.

The tomato fly, *Neoceratitis cyanecens* (which originates from Madagascar) is present in both Mauritius and Reunion. Although there has been intensive human movement between its country of origin and the Comoros and the Seychelles this species has not found its way to these two countries and has also been classified as a Moderate Risk pest as it is a major pest in Mauritius and Reunion.

The remaining species, namely *C. pedestris*, *D. demmerezi*, *D. punctatifrons* and *D. vertebratus*, due to their minor pest significance are rated as Marginal Risk species in the countries where they do not

occur. This classification is by no means exhaustive and is based on information available on fruit flies already established in the respective countries of the region (particularly Mauritius and Reunion) and will be subject to modification as new information becomes available (for example following surveys). The host range, distribution, and pest status of many of the above species may well need to be updated and could usefully be the subject of future research.

Risk of Fruit Flies Species Outside the Indian Ocean Region

The distribution of fruit flies in the Indian Ocean Region shows that exotic fruit species predominate and are more widely distributed than native species. These introduced species account for most of the damage caused by fruit flies to fruit crops and vegetables. The ecological and agricultural vulnerability of small islands to introduced organisms, including mammals, birds and plants, is widely recognised (Quammen 1996). Exotic fruit fly species have not only gained entry to the Region, but have been more successful in colonising and have led to the ecological suppression of native species such as *C. catoirii* and *D. demmerezi*. (Similarly in Hawaii there is evidence that *C. capitata*, although itself introduced, has been displaced in turn by *B. dorsalis*).

Of fruit flies occurring outside the Indian Ocean Region the genera *Bactrocera*, *Ceratitis*, and *Dacus* are of most quarantine concern. Among these the genus with the greatest quarantine significance is *Bactrocera*. As described earlier *Bactrocera dorsalis* is a global quarantine pest. Recent studies have in fact shown *B. dorsalis* to be a complex of 52 sibling species, of which 40 are considered new species and at least 8 are of economic importance. This is a matter of great concern to fruit producing countries where these species occur, requiring them to re-evaluate and revise their control strategies. In countries where these species have not been recorded, quarantine measures have been considerably strengthened to minimise the risk of their entry, establishment and spread.

Policies of strict quarantine vigilance are clearly justified by the Mauritius experience with *B. dorsalis*. Recently in Australia, another country where quarantine occupies top priority, two quarantine fruit flies, *B. philippiniensis* and *B. papaya* were detected (in 1998 and 1995 respectively). These species were also subjected to eradication campaigns at great cost. In these days of frequent international air travel the range of possible "Introduction Potential Pathways" becomes ever greater. In the 1970s the Asian species *Bactrocera carambolae* was found for the first time in the Western Hemisphere, in Surinam probably introduced through passenger luggage from Indonesia, and is the subject of an international control and eradication campaign; (Malvasi et al. 1998; CFFP 1999). This in turn demonstrates that economically important American fruit fly species such as *Anastrepha ludens*, *A. fraterculus* and *A. obliqua* must also require consideration by the Quarantine Services of the Indian Ocean Region.

CONCLUSION

The aim of this review of the quarantine risks posed by major exotic fruit flies is to create an awareness of the potential threats posed by these pests. The PRA process adopted is a simple and often subjective procedure, but this is its very strength. It is hoped that by clearly illustrating the steps involved this very transparency of PRA will help decision-makers plan to deal effectively with the threat these insects pose to the islands of the Indian Ocean Region.

Quarantine problems cannot be looked at in isolation (Black and Sweetmore 1995). Regional and International collaboration is vital if progress is to be achieved in reducing risks of fruit fly introduction and spread. To this end, countries of the region are urged to collaborate in the establishment and maintenance of the necessary fruit fly surveillance systems.

ACKNOWLEDGEMENTS

This work was carried out within the framework of the Regional Fruit Fly Programme, implemented by the Indian Ocean Commission with the financial support of the European Union. We also wish to acknowledge both the assistance of, and collaboration with the Division of Entomology of the Ministry of Agriculture, Food Technology and Natural Resources, Mauritius.

REFERENCES

BANNOCK G, BAXTER RE and DAVIS E. 1992. *Dictionary of Economics*. Penguin Books. 452 p.

BLACK R and SWEETMORE A. 1995. *Plant Quarantine: A Primer for Development Workers*. Natural Resources Institute. 41 p.

CFFP. 1999. Carambola Fruit Fly Programme. (http://www.carambolafly.com)

FAO. 1999. *Guidelines for Pest Risk Analysis*. Food and Agriculture Organisation. (http://www.fao.org/docrep/x5585e/x5585e0g.htm)

MALVASI A, SAUERS-MULLER A, MIDGARDEN D, KELLMAN V, DIDELOTD, CAPLONG P and RIBEIRO O. 1998. Regional Programme for the Eradication of the Carambola Fruit Fly in South America. p. 111. *Fifth International Symposium on Fruit Flies of Economic Importance*, 1-5 June, 1998. Penang, Malaysia. (Abstract of presentation).

QUAMMEN D. 1996. *The Song of the Dodo: Island Biogeography in an Age of Mass Extinctions.* Hutchinson. p. 702.

SEEWOORUTHUN SI, SOOKAR P, PERMALLOO S, JOOMAYE A, ALLECK M, GUNGAH B and SOONOO AR. 1998. An attempt at the eradication of the Oriental Fruit Fly, *Bactrocera dorsalis* (Hendell). p 211-218. *In*: LALOUETTE JA et al. eds. *Proceedings of the Second Annual Meeting of Agricultural Scientists, Réduit, Mauritius, 12-13 August 1997*. Réduit, Mauritius: Food and Agricultural Research Council.

WHITE IM and ELSON-HARRIS MM. 1994. *Fruit Flies of Economic Significance: Their Identification and Bionomics*. CAB International and ACIAR. 601 p. + Addendum.

WTO. 1999. *Agreement on the Application of Sanitary and Phytosanitary Measures*. World Trade Organisation.(http://www.wto.org/wto/legal/finalact.htm)

SEASONAL PROFILES IN PRODUCTION, FRUIT FLY POPULATIONS AND FRUIT FLY DAMAGE ON MANGOES IN MAURITIUS

A Manrakhan **and** *NS Price*

Indian Ocean Regional Fruit fly Programme
Ministry of Agriculture, Food Technology and Natural Resources

ABSTRACT

*A study of the seasonal variation in mango production, fruit fly populations and fruit fly damage for the mango season 1998 - 99 was carried out in Pamplemousses and Black River Districts. These districts represent areas under the two main fruit fly control regimes in Mauritius, the Male Annihilation Technique and Bait Application Technique. Ripe mango production peaked three months after the start of fruit set. Bactrocera zonata was the only species reared out of damaged mangoes. Fruit availability as well as temperature were found to be important influences on Bactrocera zonata populations in Pamplemousses. Fruit infestation levels were lower in Black River District than in Pamplemousses although the differences were not statistically significant. However, male B. zonata captures in Pamplemousses (under MAT) were found to be significantly lower than captures in Black River (under BAT). The implications of these findings are discuss*ed.

Keywords *:* fruit flies, seasonal profiles, mangoes, *Mangifera indica*, damage assessment, control, Mauritius

INTRODUCTION

The "Seasonal Profile" is a descriptive tool for considering short-term changes in crop production, pest development, pest damage and pesticide use at the field level, on an annual or crop season basis (Norton and Mumford 1993). Seasonal profiles for individual pests help indicate the development of the pest over the cropping season and decision points at various times in the season when control actions could be taken.

World production of mangoes (*Mangifera indica*) is estimated at 23.4 million tonnes (FAO 1999). In Mauritius mango fruit trees form 45% of the fruit fly host fruit tree area of Mauritius (Hammes 1982). The main varieties found in household backyards in Mauritius are Maison Rouge, Baissac, Dauphine, La Corde, Blanc, Collard, Rosa, Eugenie, Torche, Adele and Auguste (Anon. 1995). Both ripe and green mango fruits are sold in the markets of Mauritius, the prices of ripe fruits ranging from 10 MUR/unit to 4 MUR/unit over the season (Manrakhan 1998).

The Peach fruit fly, *Bactrocera zonata* (Saunders) (Diptera: Tephritidae) is considered an important fruit fly pest of mangoes in Mauritius (Burn 1997). *Ceratitis capitata* (Wied) and *Ceratitis rosa* (Karsch) have also occasionally been recorded in mangoes on the island (Burn 1997). Fruit flies attack ripe mangoes and inflict damage to the fruit either directly (larvae feeding on pulp) or by causing blemished fruit, which limits marketing possibilities (especially export of fruit) (Aluja et al. 1996).

Fruit fly control in Mauritius by the National Fruit Fly Programme is being carried out by two main techniques, The Bait Application Technique (BAT) and Male Annihilation Technique (MAT) (Soonoo et al. 1996; Permalloo et al. 1998). The BAT consists of the use of protein/insecticide bait sprays applied on regular 10-15 day rounds and kills both male and female flies. The MAT consists of the distribution of wooden plywood blocks, impregnated with male lure/toxicant, which are nailed to trees and replaced after 4 - 6 months. The lure used is Methyl Eugenol, which attracts B. zonata male flies. Malathion is the insecticide used (Soonoo et al. 1996; Permalloo et al. 1998).
Previous work by the Mauritius National Fruit Fly Programme has shown that average mango infestation levels were lower in zones of fruit fly control by BAT compared to untreated zones in 1994

- 95 (4.4% in treated zones, 19.1% in untreated zones) and 1995 - 96 (6.0% in treated zones, 24.6% in untreated zones). Mango infestation levels in 1996 - 97 were however, similar in both treated (20.4%) and untreated zones (23.0%). Most of this increase in 1996 - 97 was attributed to the cessation of BAT spraying and the placement of MAT blocks in the treated zones (Burn 1997).

A shift from a "calendar" fruit fly control approach of regular treatments to more "responsive" fruit fly management based on studies of fruit fly populations and damage in relation to fruiting patterns could help improve further the efficiency of fruit fly control schemes. Establishing more defined fruit fly control schedules for fruit trees in backyards could have important benefits both in reduction in the costs of control and a reduction in pesticide usage.

Here we report results of a study on the seasonal variation of mango production, fruit fly damage and fruit fly populations during the 1998 - 99-mango season in the Pamplemousses and Black River districts of Mauritius.

MATERIALS AND METHODS

Study area

The study was conducted in two districts of Mauritius, Pamplemousses and Black River situated in the Northwest and West of the island respectively. Both areas are under National Fruit Fly Programme control. Pamplemousses District was chosen to represent an area under mainly MAT control while Black River District was chosen to represent an area under mainly BAT control. Data on temperature and rainfall for the mango season in the two districts were obtained from the Vacoas Meteorological Station.

Host survey and fruit sampling

A total of 48 household backyards were sampled in the two districts at a ratio 7:1 (representative of 0.5% of the households present with mango variety Maison Rouge, (Rasamimanana 1998) for Pamplemousses and Black River respectively. Sampling was based on the Housing and Population Census list of Village Council Areas (VCAs) of the Ministry of Economic Planning and Development. Households were selected at random within these VCAs.

Fruit sampling

Only Maison Rouge mango variety was sampled given its predominance in backyards (Rasamimanana 1998). Information on the age of the trees surveyed was obtained from householders and only trees estimated at between 11-40 years old were sampled.

The number of ripe fruits on each tree was counted monthly across the mango season and each month 1-5% of ripe mango fruits present on each tree were sampled for further examination.

Fruit examination

Fruits were returned to the laboratory, weighed and examined in a first instance (externally for the presence of fruit fly ovipunctures and internally for larvae) to assess the number of attacked fruits in the sample. The fruits were then placed individually on a sand medium in containers until pupa formation or adult fruit fly eclosion (1-2 weeks). Any pupae or adult flies were then transferred to containers supplied with a mixture of 1:1 honey and water on crumpled paper for 5-7 days for adult emergence and full development (to facilitate accurate identification). Insects were then killed by freezing and identified.

Fruit Fly field population

Yellow dry traps baited with a solution of Methyl Eugenol / Malathion soaked onto cotton wool dental plugs were used to monitor male B. zonata numbers. A total of 15 traps were placed in the sample backyards, (10 in Pamplemousses District, 5 in Black River District) one in each VCA surveyed. Traps were examined fortnightly when the solution on the cotton wool plugs was renewed.

Statistical Analysis

Data were analysed using Excel spreadsheet software. Fruit fly damage and male B. zonata numbers in Pamplemousses and Black River districts were compared using Two Sample Student's t-test assuming unequal variances. A regression analysis using a linear model was used to determine the relationship between ripe mango availability and B. zonata male catches. Average monthly air temperatures and rainfall and male B. zonata numbers were correlated using Pearson correlation co-efficient analysis (Statsoft Inc. 1993).

RESULTS

Seasonal profiles of ripe mango production per tree, mango fruit fly damage and *B. zonata* male numbers are shown in Figures 1 and 2 for Pamplemousses and Black River districts respectively.

Seasonal variation of ripe mango production

Ripe mango production peaked in January 1999, that is three months after start of fruiting in both districts.

Seasonal variation in fruit fly damage

Only *B. zonata* flies were reared from infested mango samples collected in backyards in the two districts.

Area under MAT (Pamplemousses)

The % of mangoes damaged in this area under MAT control varied from 0% (October 1998 and February 1999) to 11% (November 1998). The number of B. zonata flies per kilogram mango fruit followed the same pattern as the %fruit fly damage with a peak in November 1998 of 22 flies per kilo. The number of flies per kilo decreased after November 1998 (**Figure 1**).

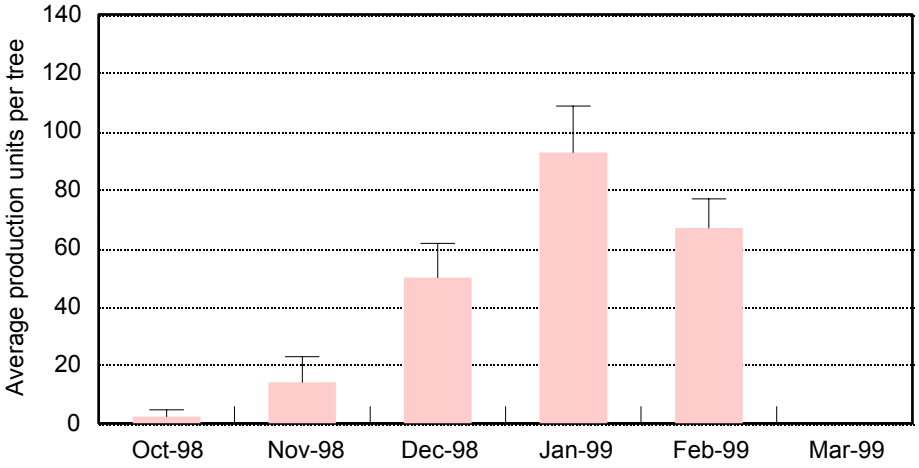
Area under BAT (Black River)

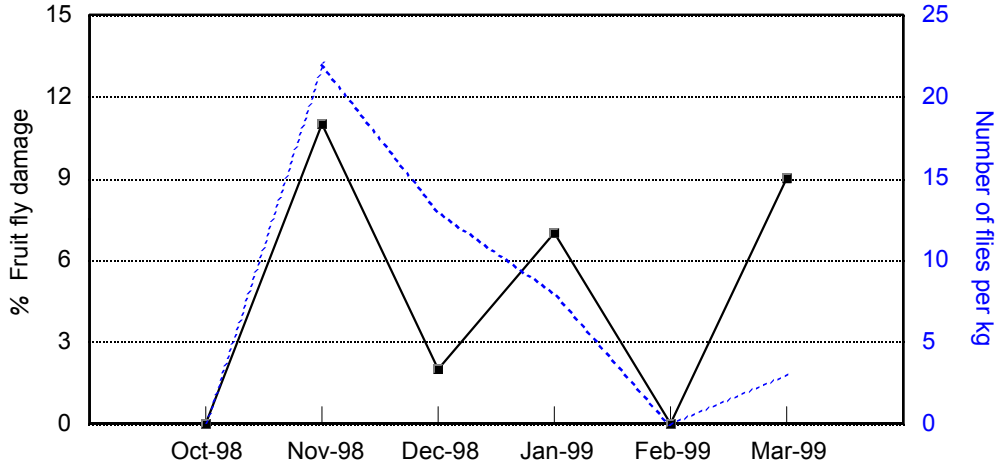
Damage on mangoes in the BAT area varied from 0% (October 1998 and November 1998) to 6% (January 1999) of fruit attacked. The number of flies per kilogram mango fruit followed the same pattern as the % fruit fly damage with a peak in January 1999 of 5 flies per kg (**Figure 2**). No statistically significant differences ($P>0.05$) in fruit fly damage were found between the area under MAT (Pamplemousses District) and the area under BAT (Black River District).

Seasonal variation in fruit fly populations

Male *B. zonata* numbers in both districts showed similar fluctuations during the study period with a major peak in January 1999 coinciding with the peak in ripe mango availability. *Bactrocera zonata* male catches throughout the study period were found to be significantly lower in Pamplemousses District than Black River District ($P<0.05$).

Figure 1 Seasonal Profile of A) mango fruit production (estimated numbers of ripe fruit per tree, Variety Maison Rouge) B) mango fruit fly damage and C) fruit fly populations (adult males) in Pamplemouuses District, an area under BAT fruit fly control.





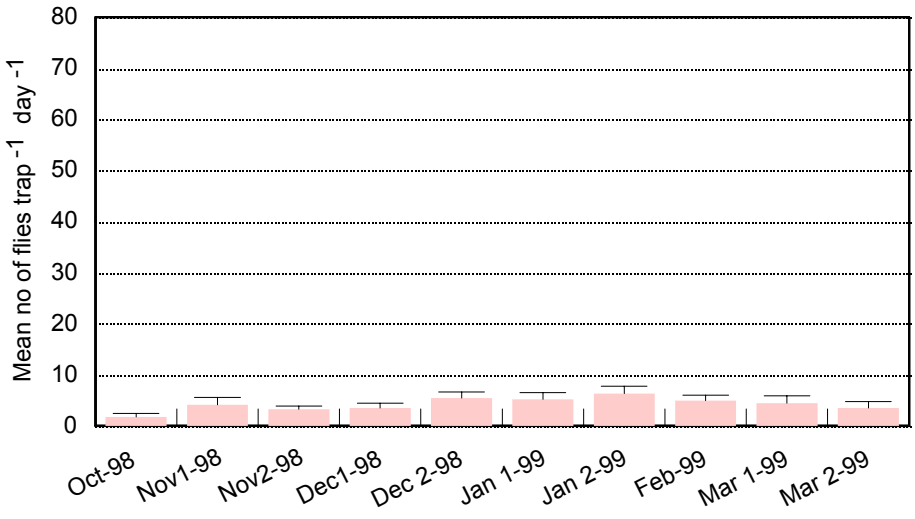
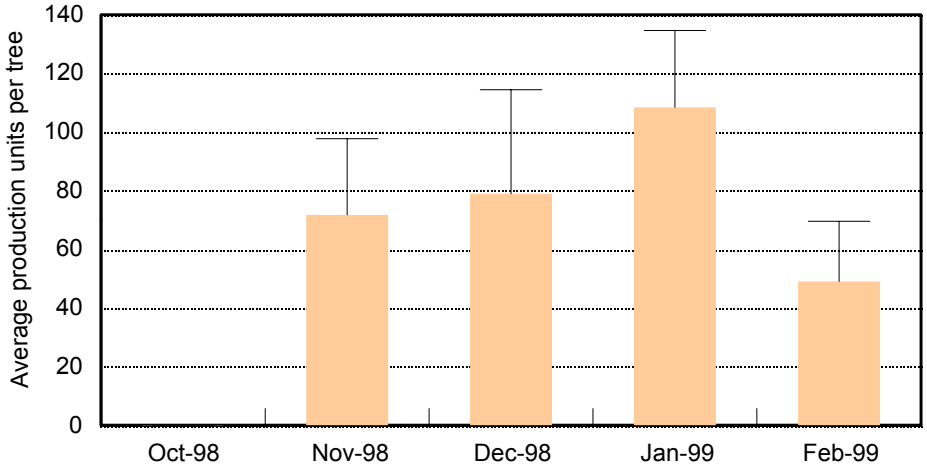
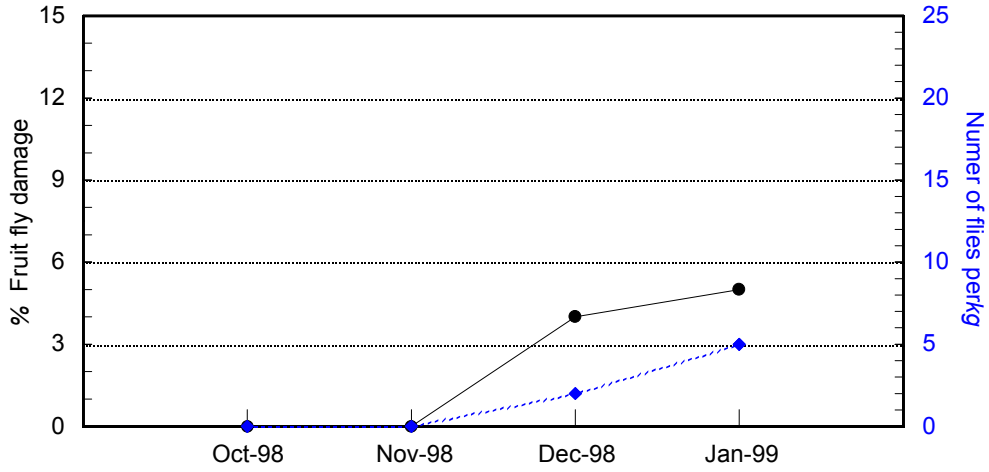
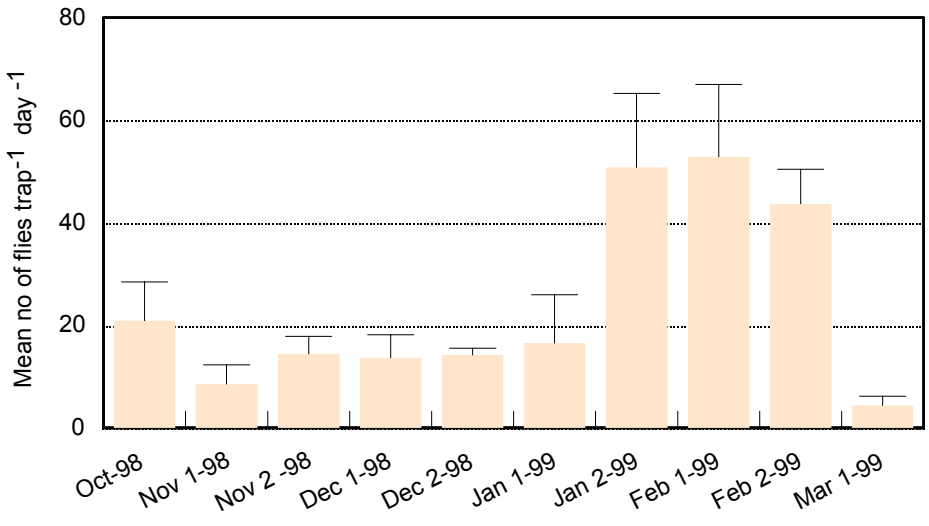


Figure 2 Seasonal Profile of A) mango fruit production (estimated numbers of ripe fruit per tree, Variety Maison Rouge) B) mango fruit fly damage and C) fruit fly populations (adult males) in Black River District, an area under BAT fruit fly control.







Influence of host fruit availability on fruit fly population fluctuations

The relationship between fruit fly numbers (males in traps) and availability (number) of ripe mangoes was studied. A good linear regression (R^2 = 0.872) was found between fly numbers and fruit availability in Pamplemousses District (**Figure 3**) however, this relationship was much poorer in Black River District (R^2 = 0.066, **Figure 4**).

Figure 3 Linear regression between ripe mango availability and *Bactrocera zonata* male numbers in Pamplemousse district (under MAT fruit fly control)

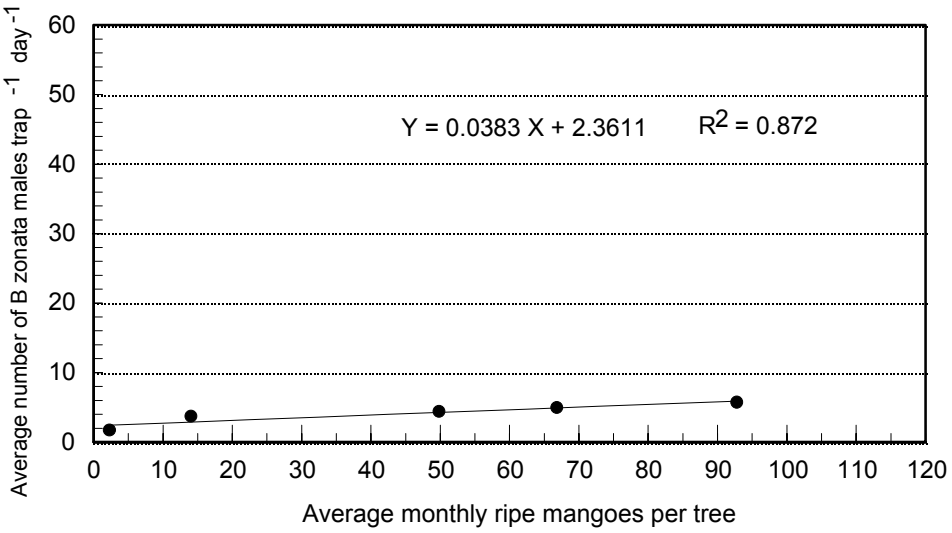
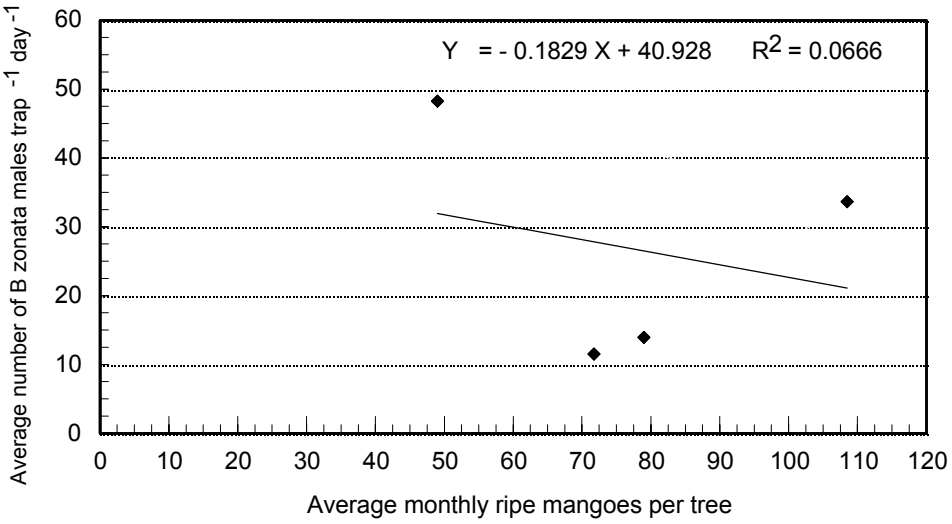


Figure 4 Linear regression between ripe mango availability and *Bactrocera zonata* male numbers in Black River district under BAT fruit fly control



Influence of environmental factors on fruit fly population fluctuations

No significant relationship between number of males captured per trap per day averaged over each month and average monthly temperature and rainfall was found at a regional level (i.e. both districts included). At the district level however, Pamplemousses had a significant correlation co-efficient ($r=0.91$, $P<0.05$) between average monthly temperature and average trap catch per day.

DISCUSSION

The study illustrated variations in ripe mango availability across the season with a peak in January, approximately three months after start of fruit set. Fruit fly (*B. zonata*) infestations varied across the season in the two districts. Both fruit fly damage (% numbers of fruit attacked) and fruit fly infestation (numbers of fruit flies per kilogram fruit) were higher in Pamplemousses (under MAT) than Black River (under BAT). These differences were 2-fold in fruit fly damage and 4-fold in levels of fruit fly infestation between the districts.

The availability of host fruit was found to be an important factor influencing fruit fly numbers in Pamplemousses District (**Figure 3**) although in Black River District such a relationship was not evident (**Figure 4**). Relationships between fruit availability and fruit fly numbers have also been observed in mango orchards in Mexico (Aluja et al. 1996). Similar studies on the Oriental Fruit Fly (Bactrocera dorsalis) by Bateman (1972) and Tan and Serit (1994) suggested that fruit fly populations were affected directly by host fruit availability.

Abiotic factors can clearly also be important in influencing fruit fly numbers for example temperature (directly or indirectly) affects fruit fly development, fecundity and mortality (Bateman 1972). A good correlation was found between temperature and male *B. zonata* catches in Pamplemousses District.

Numbers of trapped (male) flies were significantly higher in Black River than in Pamplemousses although levels of (female caused) fruit damage did not differ between the two districts. As discussed earlier the MAT for fruit fly control (used in Pamplemousses) acts on male flies whereas the BAT controls predominantly female flies. This suggests that in certain circumstances "male lure" trap catches may not be good indicators of potential fruit damage and that large captures in such traps may not indicate high fruit infestation levels. There are other types of traps available that preferentially attract and catch female flies and in addition research at developing and testing attractant lures specifically for female flies of *Ceratitis* spp. is being conducted (Kotsoyannos et al. 1998). The present work suggests that the choice of trapping techniques to be selected for the monitoring of fruit fly populations may need to consider the intended control techniques to be used and evaluated.

Implications for *Bactrocera zonata* control on mangoes in Mauritius

Back gardens in Mauritius form part of a patchwork of natural and agricultural habitats; the country also possesses commercial orchards. In addition fruits such as Indian almond (*Terminalia cattapa*), French Guava (*Psidium cattelianum* Sabine) and Jujubes (*Ziziphus mauritiana*) are important "reservoir hosts" in maintaining *B. zonata* populations. A seasonal flux can be considered to exist between such vegetation and mangoes. This implies the necessity of year round fruit fly control. However, such control could be varied depending on the availability of economically important host fruits.

In the case of mangoes this could for example, comprise MAT during the off-season with a switch to BAT during the fruiting season. These techniques differ in both their mode of action, their cost and it is felt, their efficacy. As explained earlier the MAT uses a Para pheromone to attract male flies to insecticide whereas BAT uses a protein bait to attract predominately young feeding females to insecticide. The costs of these techniques have been estimated at 86.2 MUR ha^{-1} and 116.7 MUR ha^{-1} respectively (Rasamimanana 1998). The (imported) Para pheromone is the major cost component in MAT with labour being the major cost in BAT.

Work at adjusting and refining fruit fly control procedures on mangoes, based on this information and the results presented here, is to be the subject of future collaboration between the Regional Fruit Fly Programme and the Mauritius National Fruit Fly Programme over the coming months.

ACKNOWLEDGEMENTS

This work was carried out within the framework of the Regional Fruit Fly Programme, implemented by the Indian Ocean Commission with the financial support of the European Union. We also wish to acknowledge both the assistance of and collaboration with the Division of Entomology of the Ministry of Agriculture, Food Technology and Natural Resources, Mauritius. We are also grateful to the many householders who have allowed us to work in their back-gardens.

REFERENCES

ANON. 1995. Record of fruit trees, Fruit Fly Control Target Area. Ministry of Agriculture and Natural Resources, Réduit, Mauritius.

ALUJA M, CELEDONIO-HURTADO H, LIEDO P, CABRERA M, CASTILLO F, GUILLEN J, RIOS E. 1996. Seasonal Population Fluctuations and Ecological Implications for Management of Anastrepha Fruit Flies (Diptera: Tephritidae) in Commercial Mango Orchards in Southern Mexico. *Journal of Economic Entomology* 89 (3) : 654-667.

BATEMAN MA. 1972. The Ecology of Fruit Flies. *Annual Review of Entomology* 17 : 493-518.

BURN RW. 1997. National Fly Control Programme: Report on Data Collection and Analysis. Entomology Division, Ministry of Agriculture and Natural Resources, Réduit, Mauritius.

FAO. 1999. Food and Agriculture Organisation FAOSTAT Statistics Database: Agriculture. http://apps.fao.org/cgi-bin/nph-db.pl?subset=agriculture.

HAMMES C. 1982. Projet de lutte contre la mouche du natal *Pterandus rosa* (Karsch), Diptera: Trypetidae a L'ile Maurice. Rapport Final, Ministry of Agriculture, Fisheries and Co-operatives, Réduit, Maurice.

KATSOYANNOS BI, PAPADOPOULOS NT, HEATH RR, HENDRICHS J, and KOULOUSSIS NA. 1998. Evaluation of synthetic food-based attractants for female Mediterranean Fruit Flies (Diptera: Tephtitidae) in McPhail traps. Poster presented at: *The Fifth International Symposium on Fruit Flies of Economic Importance: Current Global Sc*enario, 1-5 June 1998, Penang, Malaysia.

MANRAKHAN A. 1998. Economic Basis for Improved Efficiency of Fruit Fly Management Actions. Indian Ocean Commission Regional Fruit Fly Programme, Researcher Report, January-March 1999. Entomology Division, Ministry of Agriculture, Fisheries and Co-operatives, Réduit, Mauritius.

NORTON GA and MUMFORD JD. 1993. *Decision Tools for Pest Management*. CAB International, U.K. p.279.

PERMALLOO S., SEEWOORUTHUN, SI., JOOMAYE A., SOONOO AR., GUNGAH B., UNMOLE L. and BOODRAM R. 1998. An Area Wide Control of Fruit Flies in Mauritius. p 203-210. In: LALOUETTE JA., BACHRAZ DY., SUKURDEEP N. and SEEBALUCK BD. eds. *Proceedings of the Second Annual Meeting of Agricultural Scientists, Réduit, Mauritius, 12-13 August 1997*. Réduit, Mauritius: Food and Agricultural Research Council.

RASAMIMANANA H. 1998. Base Economique pour l'amelioration de la gestion des mouches des fruits. Rapports d'activités du Programme Regional de Recherche Appliquee sur les mouches des fruits, Janvier - Mars 1998. Indian Ocean Commission Regional Fly Programme. Entomology Division, Ministry of Agriculture, Fisheries and Co-operatives, Réduit, Mauritius.

SOONOO AR, SMITH ESC, JOOMAYE A, PERMALLOO S. and GUNGAH B. 1996 A Large Scale Fruit Fly Control Programme in Mauritius. p 52 – 60. *In:* CHUA TH. and KHOO SG. eds. *Problems and Management of Tropical Fruit Flies*. *Proceedings of the Second Symposium on Tropical Fruit Flies*, 8-9 May 1995, Kuala Lumpur, Malaysia.

STATSOFT INC. 1993. Statistics for Windows. *Release 4.5*

TAN KENG-HONG and SERIT MUNEY. 1994. Adult Population Dynamics of Bactrocera dorsalis (Diptera: Tephritidae) in relation to host phenology and weather in two villages of Penang Island, Malaysia. Environmental Entomology 23 (2) : 267-275.

LOCAL PRODUCTION OF PROTEIN BAIT FOR USE IN FRUIT FLY MONITORING AND CONTROL

S Gopaul* and *NS Price

Indian Ocean Regional Fruit fly Programme

Ministry of Agriculture, Food Technology and Natural Resources

ABSTRACT

Protein bait prepared by the acid hydrolysis of yeast from brewery waste is imported by the Ministry of Agriculture for use in fruit fly monitoring and control. A protein bait was prepared locally using yeast brewery waste from Mauritius Breweries transformed by a process of heat autolysis and enzymatic proteolysis. This bait was compared with imported bait in replicated field trials using McPhail traps.

Both preparations attracted significantly more fruit flies than the water controls. In general there were no significant differences between the locally produced bait formulations and the imported bait in numbers of fruit flies trapped. These results demonstrate the potential of locally produced bait as a cheaper alternative in fruit fly control. Topics requiring further investigation are discussed.

Keywords : fruit flies, protein baits, protein hydolysate, yeast autolysate, monitoring, control, Mauritius

INTRODUCTION

Within Mauritius the control and monitoring of fruit fly populations is based on two main technologies (Soonoo et al. 1996; Permalloo et al. 1998)). The first technology uses Para pheromone male attractants in traps (that monitor male numbers) and in the Male Annihilation Technique (MAT) in which wooden blocks impregnated with Para pheromone and Malathion insecticide are placed in trees. Control occurs as males are attracted to these blocks and ingest both the Para pheromone and the insecticide.

The second technology, the Bait Application Technique (BAT) relies on protein baits whose use in fruit fly monitoring and control is based on their attractiveness as a food source (Roessler 1989). A mixture of protein bait and Malathion insecticide is sprayed in "spots" of 40 ml on foliage or tree branches. Fruit flies are attracted to these spots, and are killed as a result of ingesting insecticide during feeding on the bait. In Mauritius protein hydrolysate bait is also used in monitoring of fruit fly populations by "McPhail" traps, in which a quantity of bait solution (usually 400 ml) is placed in the trap attracting fruit flies to enter and eventually drown in the liquid.

Protein hydrolysate is (excluding the cost of labour) the biggest cost component of BAT in Mauritius comprising approximately 15 % of total costs (and 75% of non-labour costs) (Rasamimanana 1997). The protein hydrolysate bait currently used is imported from the United Kingdom at a (duty-free) cost of 130 MUR a litre and at its greatest extent the Mauritian National Fruit Fly Programme was spending the equivalent of 1,400,000 MUR per year on imported protein hydrolysate bait. Clearly the ability of Mauritius to produce its own, substitute, bait could make a major contribution to reducing the cost and enhancing the sustainability of fruit fly control activities in the country.

For this reason the Indian Ocean Regional Fruit Fly Control Programme has initiated work into the local production of protein bait from locally available brewery yeast waste.

MATERIALS AND METHODS

Protein Bait Preparation

Brewery yeast waste ("Phoenix" Beer and Guinness) was obtained courtesy of Mauritius Breweries. Data supplied by the brewery show "Phoenix" Beer waste to consist of $700x10^6ml^{-1}$ cells of *Saccharomyces cerevisae* at pH of 4.5-5.0 and dry matter content of 55-60%. Brewery waste was placed in 2.5l Winchester bottles and pasteurised in an oven at 70^0C for 9 hrs then allowed to cool overnight to ambient temperatures. This process causes a degree of yeast cell autolysis and a release of cell contents. Proteolysis of released yeast cell proteins then occurred by the addition of 10g of Papain enzyme powder (BDH Chemicals, UK) to each bottle (i.e. $4gl^{-1}$ pasteurised liquid) and replacing bottles in the oven for a further 9 hrs at 70^0C. Bottles were then allowed to cool. Potassium Sorbate (as a preserving agent) was then added at a rate of 5g per Winchester bottle (ie.2%) and the liquid allowed to settle. The process results in the formation of a clear brown "supernatant" and cloudy "sediment" containing a mixture of the supernatant and"debris" of settled cell wall material. Each fraction represents about 50% of the total volume in the bottle. Analysis of these supernatant fractions showed the processed "Beer waste" to have a protein content of 7.0% and the processed "Guinness waste" a protein content of 9.7%.

Field Trials

These locally formulated protein autolysate baits were compared with the currently used (imported) protein hydrolysate bait in three field trials. Trials were conducted in mango orchards at the Horticultural Division Agricultural Centres of Arsenal and Bois Marchand and in wild growing mango trees on State Land at Dauguet.

Trials used McPhail traps treatments comprising the following different bait solutions:

Water (as a Control)
Protein hydrolysate (7.5% Commercial product).
Beer Waste (7.5% locally produced Beer autolysate "supernatant")
Guinness Waste (7.5% locally produced Guinness autolysate "supernatant")
Beer "debris" (7.5% locally produced Beer "debris")
Guinness "debris" (7.5% locally produced Guinness "debris")

Borax was added ($22.5gl^{-1}$) to all solutions to prevent decay of trapped insects.

Six McPhail traps were suspended in mango trees approximately 25m apart and 400ml of a different prepared bait solution (or water) added to each trap. After 7 days traps were examined and trapped fruit flies counted and categorized according to species and sex. Traps were then washed with water and baits renewed; each trap was moved to a new position within the experimental site following a prepared experimental design. The process was repeated for 6 weeks. The trials thus each constituted a Randomised Complete Block Design of 6 treatments and 6 replicates (weeks). Fruit Fly counts were then expressed as numbers of insects trapped per day and log transformed (log (n+1)) prior to conducting Analysis of Variance and applying the Duncan's' Multiple Range Test.

RESULTS

Results are presented in **Tables 1 - 3**. Figures represent un-transformed means. The Duncan's Multiple Range Test was conducted on log-transformed data

The most abundant fruit fly species in these trials was *Bactrocera zonata*, ("The Peach Fruit Fly") present at both Arsenal and Bois Marchand. *Ceratitis rosa* ("The Natal Fruit Fly") was found at Arsenal and at Dauguet whilst "The Melon Fly", *Bactrocera cucurbitae* occurred at Bois Marchand. When present other species occurred in such low numbers that they have been excluded from further analysis.

In all trials the water Control baited traps recovered very few flies. This both showed the suitability of water as a "control" and the adequacy of the experimental procedure to demonstrate differences between baits. In all trials commercial protein hydrolysate baited traps recovered significantly more fruit flies of all species than Control (water baited) traps. No statistically significant differences were observed between commercial protein hydrolysate bait and any of the locally produced baits in numbers of *B. zonata* trapped at either Arsenal or Bois Marchand (**Tables 1 and 2**).

Table 1 Mean number of fruit flies caught (per trap per day) in McPhail traps in the Mango Orchard at Arsenal using different Protein Baits

Fruit Fly species	Treatment					
	Water (Control)	Protein Hydrolysate	Beer Autolysate	Guinness Autolysate	Beer "Debris"	Guinness "Debris"
Ceratitis rosa (males)	0.0 a	4.5 b	1.8 ab	1.8 ab	0.6 a	2.2 ab
Ceratitis rosa (females)	0.0 a	5.5 b	2.3 ab	0.8 a	4.8 b	0.5 a
Ceratitis rosa (total)	0.0 a	10.0 b	4.2 ab	2.7 acd	5.4 bcd	2.7 ad
Bactrocera zonata (males)	0.3 a	9.3 b	6.0 b	5.8 b	2.4 b	5.2 b
Bactrocera zonata (females)	0.5 a	18.5 b	17.5 b	11.3 b	17.6 b	19.8 b
Bactrocerazonata (total)	0.8 a	27.8 b	23.5 b	17.2 b	21.4 b	25.0 b

Data presented un-transformed. ANOVA was conducted on log (n+1) values. Means within rows followed by the same letter are not significantly different (p=0.05) according to the Duncan's Multiple Range Test.

Table 2 Mean number of fruit flies caught (per trap per day) in McPhail traps in the Mango Orchard at Bois Marchand using different Protein Baits.

Fruit Fly species	Treatment					
	Water (Control)	Protein Hydrolysate	Beer Autolysate	Guinness Autolysate	Beer "Debris"	Guinness "Debris"
Bactrocera zonata (males)	1.2 a	13.7 b	7.0 b	7.2 b	10.6 b	9.2 b
Bactrocera zonata (females)	0.2 a	26.0 b	12.7 b	19.0 b	20.0 b	18.2 b
Bactrocera zonata (total)	1.3 a	39.7 b	19.7 b	26.1 b	30.6 b	27.3 b
Bactrocera cucurbitae (males)	0.5 a	12.0 b	1.2 a	1.7 a	1.2 a	0.8 a
Bactrocera cucurbitae (females)	0.3 a	11.5 b	1.7 a	2.7 a	1.6 a	1.8 a
Bactrocera cucurbitae (total)	0.8 a	23.5 b	2.8 a	4.3 a	2.8 a	2.7 a

Data presented un-transformed. ANOVA was conducted on log (n+1) values. Means within rows followed by the same letter are not significantly different (p=0.05) according to the Duncan's' Multiple Range Test

Numbers of *C. rosa* trapped using locally produced baits were generally greater than those trapped with the Control (water bait) but less than those trapped with commercial protein hydrolysate bait (**Tables 2 and 3**). Generally however, differences were not statistically significant.

Table 3 Mean number of fruit flies caught (per trap per day) in McPhail traps placed in Mango trees at Dogey using different Protein Baits.

Ceratitis rosa	Treatment					
	Water (Control)	Protein Hydrolysate	Beer Autolysate	Guinness Autolysate	Beer "Debris"	Guinness "Debris"
Males	0.2 a	3.0 b	2.0 ab	1.2 ab	1.3 ab	0.7 a
Females	0.2 a	3.2 b	1.2 ab	1.5 ab	1.0 ab	0.0 a
Total	0.3 a	6.2 b	3.2 ab	2.7 ab	2.3 ab	0.7 a

Data presented un-transformed. ANOVA was conducted on log (n+1) values. Means within rows followed by the same letter are not significantly different (p=0.05) according to the Duncans' Multiple Range Test

At Bois Marchand commercial protein hydrolysate attracted significantly more *B. cucurbitae* than either the Control (water bait) or any of the locally prepared baits (**Table 2**). Locally prepared baits were no more effective at trapping *B. cucurbitae* than the Control (water). In general protein baits trapped more females than male flies. In the case of the most abundant species, *B. zonata* female flies formed between 64% and 82% of total flies trapped.

DISCUSSION

Attractant / insecticide mixtures have been used with success in fruit fly control since the turn of the century (Roessler 1989). However, our knowledge of the how such mixtures work, in particular the components and mechanisms involved in the attraction of fruit flies to baits is still poorly understood.

In the first half of the century bait mixtures of carbohydrates and other fermenting substances (such as molasses, sugars etc.) in combination with inorganic insecticides such as lead arsenate were used (Roessler 1989). In the 1950's protein hydrolysate baits mixed with parathion were first used in Hawaii (Steiner 1952). Malathion was later used with protein hydrolysate baits in very successful campaigns against the Medfly (*Ceratitis capitata*) in Florida (Steiner et al. 1961).

These early protein baits were usually produced by the acid hydrolysis of plant proteins (usually derived from maize) however, increasingly yeast protein, making use of by-products of beer brewing has been used (Allwood 1997). Acid hydrolysis (generally with concentrated hydrochloric acid) can result in a substance with a low pH, requiring neutralization, which may cause salt to form in the bait which can in turn cause problems of phytotoxicity when used as a spray. Increasingly yeast wastes autolysed by the use of enzymes are being used in bait production (Allwood 1997).

The process used in the present work involves a pasteurisation of brewery waste, which it is assumed leads to a degree of yeast cell autolysis, followed by proteolysis of the cell proteins thus released. The use of brewery waste as a raw material in the making of protein bait is a relatively new concept. Brewery waste was used in the production of a bait in Malaysia, but for commercial reasons the procedures have not been fully published (Vijaysegaran pers.comm.). The procedures used by us in this preliminary work in Mauritius, have been based on methods outlined by Lloyd and Drew (1997) simplified to take account of local conditions.

Considering the still limited state of knowledge of what constitute attractive protein baits a detailed knowledge of the different processes of bait production is largely irrelevant, the question is whether they work. To evaluate this "the only reliable procedure is the use of bioassays with live flies" (Roessler 1989).

It is clear from the results presented (**Tables 1 - 3**) that locally produced protein autolysate baits were generally as attractive in McPhail traps as the currently used imported protein hydrolysate. This was particularly the case for the most abundant (and most important economically) fruit fly attacking fleshy fruits in Mauritius, *B. zonata*. No significant differences were observed in numbers of this species trapped between the imported protein hydrolysate bait and any of the locally produced protein

autolysate formulations. This contrast with findings obtained using brewers waste derived baits in Malaysia. In Malaysia locally produced bait made from Guinness waste was found more effective than that derived from ordinary beer waste (Vijaysegaran pers.comm.).

In these trials, in almost all cases, both imported protein hydrolysate bait and locally produced protein autolysate bait attracted more female than male fruit flies (**Tables 1–3**). This conforms with findings of other researchers and the presumed role of protein baits as a food attractants and sources, in particular to immature females (Allwood 1997).

A surprising and potentially interesting finding was the response of *B. cucurbitae* in the Bois Marchand trial. In contrast to both *B. zonata* and *C. rosa* in trials at both Arsenal and Dauguet this species was significantly less attracted to the locally produced protein autolysate bait than to the imported protein hydrolysate. Locally produced protein autolysate bait was only slightly (and statistically insignificantly) more attractive to this species than the water Control. *B. cucurbitae* has a very wide host range, including non-Cucurbits (although none have so far been identified in Mauritius) and also has the ability to attack non-fruiting plant parts, such as flowers, stems and even tap-roots (White and Elson-Harris 1994). Clearly this observation needs repeating for validation but has the potential to provide insights into the attractive substances present in baits. Work using locally produced baits in the control of *B. cucurbitae* is shortly to be conducted by the Mauritius National Programme.

Research in the preparation of protein autolysate bait is continuing. The work reported here used laboratory grade papain enzyme which is expensive. Further work has used cheaper food-grade papain enzyme obtained from both the UK and from India. With a view to reducing costs work is examining in particular the minimum enzyme concentrations needed in post-pasteurisation proteolysis.

Both imported and locally produced bait solutions used in these trials were prepared in the same manner. However, the imported bait stock solution has a protein concentration 75% compared with concentrations of only 7.0% - 9.7% protein for the locally produced baits. Thus the imported bait solution as used in these trials had a protein concentration of approximately 5.5% compared with concentrations of only 0.5% - 0.7% for the locally produced bait solutions. Other workers have also found yeast autolysates more attractive than bait produced by acid hydrolysis, possibly due to the presence of salts in the latter (Allwood 1997). This again highlights the complexity of the biochemical and physiological mechanisms behind the attraction of fruit flies to protein baits.

All work so far has used McPhail traps to assess the attractiveness of different bait formulations in fruit fly monitoring. Clearly field-testing of locally produced bait is a priority. Only by being able to use locally produced bait in large-scale fruit fly control programmes will significant savings accrue to fruit fly control activities in Mauritius.

Such field-testing is to be the object of collaboration between the Mauritius National Fruit Fly Programme and the Indian Ocean Fruit Fly Programme over the coming months.

ACKNOWLEDGMENTS

The authors would like to thank Mauritius Breweries for supplying brewery waste used in this work and the Agricultural Chemistry Division for the use of laboratory equipment and facilities. Thanks also to the staff of the Agricultural Centres of Arsenal and Bois Marchand for their collaboration. This work was carried out within the framework of the Regional Fruit Fly Programme, implemented by the Indian Ocean Commission with the financial support of the European Union.

We also wish to acknowledge both the assistance of and collaboration with the Division of Entomology of the Ministry of Agriculture, Food Technology and Natural Resources, Mauritius.

REFERENCES

ALLWOOD J. 1997. Control Strategies for Fruit Flies (Family Tephritidae) in the South Pacific. p.171 – 178. *In:* ALLWOOD AJ and DREW RAI eds. *Management of Fruit Flies in the Pacific*. A regional symposium, Nadi, Fiji 28-31 October 1996. ACIAR Proceedings No. 76.

LLOYD A and DREW RAI. 1997. Modification and Testing of Brewery Waste Yeast as a Protein Source for Fruit Fly Bait. p 192 – 198. *In:* ALLWOOD AJ and DREW RAI eds. *Management of Fruit Flies in the Pacific*. A regional symposium, Nadi, Fiji 28-31 October 1996. ACIAR Proceedings No. 76.

PERMALLOO S, SEEWOORUTHUN SI, JOOMAYE A, SOONOO AR, GUNGAH B, UNMOLE L and BOODRAM R. 1998. An Area Wide Control of Fruit Flies in Mauritius. p 203-210. *In*: LALOUETTE JA, BACHRAZ DY., SUKURDEEP N. and SEEBALUCK BD. eds. *Proceedings of the Second Annual Meeting of Agricultural Scientists, Réduit, Mauritius, 12-13 August 1997*. Réduit, Mauritius: Food and Agricultural Research Council.

RASAMIMANANA H. 1997. Base Economique pour l'Amélioration de la Gestion des Mouches des Fruits. p 31 + Annexes. Indian Ocean Regional Fruit Fly Programme Report of Activities, September – November 1997.

ROESSLER Y. 1989. Insecticidal Bait and Cover Sprays. p329 – 336. *In:* ROBINSON AS. And HOOPER G. eds. *Fruit Flies: Their Biology, Natural Enemies and Control*. World Crop Pests Volume 3B. Elsevier.

SOONOO AR, SMITH ESC, JOOMAYE A, PERMALLOO S and GUNGAH B. 1996 A Large Scale Fruit Fly Control Programme in Mauritius. p52 – 60. *In:* CHUA TH. and KHOO SG. eds. *Problems and Management of Tropical Fruit Flies. Proceedings of the Second Symposium on Tropical Fruit Flies*, 8-9 May 1995, Kuala Lumpur, Malaysia.

STEINER LF. 1952 Fruit fly control in Hawaii with poison bait sprays containing protein hydrolyzates. *Journal of Economic Entomology* 45: 838-843.

STEINER LF, ROHWER GG, AYERS EL and CHRISTENSON LD. 1961 The role of attractants in the recent Mediterranean fruit fly eradication program in Florida. *Journal of Economic Entomology* 54: 30-35.

WHITE I and ELSON-HARRIS MM. 1994 *Fruit Flies of Economic Significance: Their Identification and Bionomics*. CAB International with ACIAR. p 601 + Addendum.

EVALUATION OF THE GENETIC BASE OF SUGARCANE CULTIVARS AND STRUCTURATION OF THE DIVERSITY AT THE CHROMOSOME LEVEL USING MOLECULAR MARKERS.

N Jannoo, L Grivet, A Dookun, A D'Hont, JC Glaszmann

Mauritius Sugar Industry Research Institute

ABSTRACT

Molecular diversity was analysed among 160 sugarcane clones consisting of 109 modern cultivars mainly from Barbados and Mauritius and 51 of S. officinarum species, which is the major source of genes in modern cultivars. Twelve low copy nuclear RFLP probes scattered over the genome were applied. Although only a few clones of S. officinarum were used in the genealogy of sugarcane cultivars, they encompassed most of the diversity observed within this species. Moreover, more than 80% of the markers present in the whole S. officinarum sample were also present in cultivars due probably to high heterozygosity and polyploidy. A distinct separation was observed between the two main groups of cultivars, Barbados and Mauritius. This appeared essentially due to S. spontaneum alleles present in Mauritian cultivars and absent in Barbadan ones.

Linkage disequilibrium was also investigated in a population of 59 cultivars using 38 RFLP probes regularly distributed over the sugarcane genome map. Associations were observed between 33 loci separated by less than 10 cM. This disequilibrium is interpreted as the result of the foundation bottleneck related to the history of sugarcane cultivars. A practical application is that markers can be used to track known QTL in modern breeding materials without the necessity to repeatedly study segregating progenies.

Key words: sugarcane, *Saccharum officinarum,* genetics, molecular markers, diversity, polyploidy, RFLP, linkage disequilibrium, Barbados, Mauritius.

INTRODUCTION

Sugarcane is the main sugar-producing crop. It is a large grass cultivated in tropical and subtropical regions and belongs to the genus *Saccharum* of the Poaceae family. The genus *Saccharum,* characterised by a high ploidy level and aneuploidy, formally comprises six species: *S. spontaneum* L., *S. robustum* Brandes and Jesweit ex Grassl, *S. officinarum* L., *S. barberi* Jesw., *S. sinense* Roxb. and *S. edule* Hassk. Two species, *S. officinarum* (2n=80) (Bremer 1930; Li and Price 1967; Price and Daniels 1968; Jagathesan et al. 1970) and *S. spontaneum* (2n=40 to 128) (Sreenivasan et al. 1987) are at the origin of commercial sugarcane cultivars. *S. officinarum* also known as the 'noble' cane is the sugar producing species. New Guinea is supposed to be its centre of origin. *S. spontaneum* is a wild species, poor in sugar but is adaptable to different environments and is resistant to several diseases. It has a wide distribution from Japan to the Mediterranean and Africa, with India as its centre of origin.

Early in this century, breeders in Java and India produced interspecific hybrids between *S. officinarum* and *S. spontaneum* and backcrossed twice with *S. officinarum* as the recurrent parent. This process is called 'nobilisation'. The resulting clones were highly productive (Roach 1972). However, the nobilisation has increased the genome complexity. During this process, *S. officinarum* clones transmitted their somatic chromosome number during the first hybridisation and the first backcross contrarily to the *S. spontaneum* ones. It is from the BC2 onward that chromosome transmission becomes normal. Therefore, nobilised clones are highly polyploid and are characterised by a high chromosome number (2n=100 to 130), with roughly 80% of the genome derived from *S. officinarum* and the remaining from *S. spontaneum* (Price 1957; Roach 1969). Interspecific intrachromosomal recombination can be observed in modern cultivars. Modern sugarcane cultivars are derived largely from intercrossing of these first nobilised hybrids and their progenies. Between 12 to 15 years are

necessary for complete evaluation before variety release. Thus, modern cultivars result from less than ten meioses (between 5 and 7) since the first interspecific crosses.

The number of initial parental contributors, *S. officinarum* and *S. spontaneum*, is very small (Arcenaux 1967) and is a matter of concern among sugarcane breeders. This has also been confirmed by various molecular studies carried out on a small sample (Lu et al. 1994a, b). The particular history of sugarcane breeding, a foundation effect combined to a low number of meioses, suggest that modern cultivars may have kept traces of the initial genotypic structure of the first parents. A previous study has detected the existence of linkage disequilibrium among cultivars (Lu et al 1994 b).

The aim of this study was, in a first step, to evaluate the diversity existing within a sample of cultivars from different breeding stations and of clones labelled as *S. officinarum* from the area of origin and diversity of this species. Due to the predominance of *S. officinarum* in the genome of cultivars and to the importance of the agronomic characters inherent to this species, it was important to evaluate the diversity existing within this species and the proportion of this diversity present in the cultivars. In a second step, the organisation of this diversity at the chromosome level was studied in cultivars through the investigation of linkage disequilibrium.

MATERIALS AND METHODS

Plant material

The material analysed consisted of 51 clones of *S. officinarum* L. and 109 cultivars, which are listed in **Tables 1**. The clones of *S. officinarum* were mainly from the area of origin and diversity, New Guinea, and the surrounding Indonesian and Pacific islands. Clones involved in the genealogy of modern cultivars, as described by Arcenaux (1967), were also included and are referred to as genealogy clones. The geographical origin of these clones is uncertain. Cultivars originated mainly from two sugarcane breeding stations located in Barbados and Mauritius. Cultivars from other breeding stations and some of the first interspecific hybrids, mainly from India and Java and present in the genealogy of most modern cultivars, were also included.

All the 160 clones were used for investigating the organisation of the diversity at the population level, whereas the analysis of linkage disequilibrium was carried out on only a subset of the cultivars. It consisted of 59 cultivars mainly from the Mauritian breeding program. A few clones from other breeding stations were included: seven from Réunion island, two from Barbados, one each from Australia, Hawaii, Taiwan and eight from the first interspecific hybrids (**Table 1**). Clones were obtained from the world collection at Canal Point, Florida, USA, the working collections of WICSCBS (West Indies Central Sugar Cane Breeding Station) in Barbados, BSES (Bureau of Sugar Experiment Stations) in Australia, MSIRI (Mauritius Sugar Industry Research Institute) in Mauritius and CIRAD (Centre de coopération Internationale en Recherche Agronomique pour le Développement) in Guadeloupe and Montpellier, France.

DNA isolation and restriction enzyme analysis

Sugarcane leaves were freeze-dried and total DNA was extracted according to the protocol of Hoisington (1992). Ten µg of DNA was restricted with two out of the three enzymes: *Dra*I, *Hin*dIII and *Sst*I. The restricted DNA was purified by phenol/chloroform extraction and DNA fragments were separated in 0.8% TAE agarose gels at 1.7 V/cm for 24h. After depurination in 0.25 N HCl for 10 min, gels were Southern blotted onto a Nylon membrane (Hybond N+) in 0.4 N NaOH. Prehybridisation (at least 4h at 65°C) was carried out in 5X SSC, 0.2% SDS (w/v), 1X Denhardt's and 0.1mg/ml of sheared salmon sperm DNA. Hybridisation (overnight at 65°C) was performed with the same solution as for prehybridisation plus 10% dextran sulfate (w/v) and the labelled probes. Membranes were washed for 5 min in 2 X SSC, 0.5% SDS (w/v) at room temperature, two times for 30 min in 0.5 X SSC, 0.1% SDS (w/v) at 65°C and two times for 30 min in 0.1 X SSC, 0.1% SDS (w/v) at 65°C, and exposed to X-ray film (Fuji NIF New RX) at –80°C for 5 days with one intensifying screen.

Table 1 List of *S. officinarum* and cultivars used in the diversity analysis

Clones	Origin	Clones	Origin	Clones	Origin
S. officinarum (genealogy)		*M377/56		DB7869	Barbados
Cristalina	New Guinea	*M351/57		Cultivars Australia	
Loethers	-	*M555/60		*Q96	
Bandjermasin Hitam	-	*M907/61		Q90	
EK28	-	*M574/62		Q110	
Kaludai Boothan	-	*M2173/63		Q117	Australia
Vellai	-	*M376/64		Q124	
Mauritius Guingan	-	*M657/66		Q138	
Fiji 24	-	*M1156/66		Q141	
Black Cheribon	New Guinea	*M3035/66		Q155	
Badila		*M695/69		Cultivars Réunion	
Korpi	-	*M292/70		*R472777	Fiji
Mp131	Mauritius	*M1205/70		*R570	
Bambou Rose		*M1557/70		*R575	
Other *S. officinarum*		*M298/71	Mauritius	*R576	Reunion island
28 NG 285		*M1030/71		*R577	
28 NG 288		*M1236/71		*R578	
51 NG 113		*M50/75		*R579	
51 NG 142		*M134/75		Other cultivars	
51 NG 153		*M536/75		SP70-1284	
57 NG 11		*M791/75		SP71-6163	Brazil
57 NG 16		*M1077/75		SP79-1011	
57 NG 30		*M1176/77		N12	
57 NG 52		*M52/78		N14	South Africa
57 NG 57		*M624/78		N53216	
57 NG 68	New Guinea	*M725/78		FR832035	Guadeloupe
57 NG 123		*M1658/78		ROC5	Taiwan
57 NG 198		*M2077/78		CP44-101	USA
77 NG 66		*M2229/80		First interspecific hybrids	
77 NG 142		Cultivars Barbados		*Co213	
IJ 76-291		*B3337		*Co281	
IJ 76-316		*B34104		*Co290	India
IJ 76-325		B37161		*Co312	
IJ 76-432		B41211		Co6415	
IJ 76-447		B41227		*H32-8560	Hawaii
IJ 76-468		B45151		NCo310	India
IJ 76-521		B4744		NCo376	
IS 76-116		B51129		*POJ2878	Java
IS 76-117		B52107		*PT4352	
IS 76-203		B54142		*S17	Taiwan
IS 76-226	Indonesia	B5992			
IK 76-33		B62163			
IK 76-95		B63118			
IM 76-244		B69379			
Fiji 23		B69566			
Fiji 38		B70532			
Fiji 44		B74541	Barbados		
Fiji 45		B77602			
Fiji 63	Pacific islands	B79474			
NC – 24		B8008			
NC – 30		B80251			
NC – 42		B80689			
NC – 99		B82139			
Cultivars Mauritius		B82238			
*M134/32		B83345			
*M213/40		BJ7015			
*M241/40		BJ7452			
*M147/44		BJ7465			
*M31/45	Mauritius	BT73686			
*M202/46		BT74209			
*M93/48		DB63113			
*M305/51		DB7047			
*M356/53		DB7160			
*M13/56		DB75159			

Clones used in linkage disequilibrium are indicated with a *.

DNA probes

The probes were selected taking advantage of the sugarcane map of the cultivar R570 (Grivet et al. 1996). Twelve probes were used for analysing the diversity at the population level (**Table 2**). They were chosen in order to cover the whole genome. Twenty-six additional probes were applied to investigate the organisation of the diversity at the chromosome level (**Table 2**). All 38 probes were used for the linkage disequilibrium study in order to be regularly distributed over the genome, and to yield hybridisation patterns with strong well-resolved bands. The probes were derived from sugarcane genomic DNA libraries (SSCIR and SG probes) and from a cDNA library (CDS probes) (da Silva et al. 1993; Grivet et al. 1996). All but three of them were present in one copy on the sugarcane genome; the three others were duplicated on two different linkage groups. The probes were labelled with ^{32}PαdCTP (ICN Pharmaceuticals, Inc.) using the Amersham Megaprime labelling kit.

Table 2 List of probes used

Probes	Diversity	Probes	Diversity	Probes	Diversity	Probes	Diversity
SSCIR73	*	SSCIR101		SSCIR194		SSCIR86	
SSCIR69		SG12		CDSR8	*	SSCIR76	*
CDSC52	*	SSCIR77	*	SSCIR105		SG305	
SSCIR79	*	CDSR120		SSCIR107		SSCIR190	*
SSCIR103	*	SSCIR217		SSCIR148		SG298	
SSCIR172		SG29	*	CDSC57		SSCIR166	
SG99	*	CDSR132		SG54	*	SSCIR257	
SSCIR60		SG426		CDSR35		SSCIR91	
SSCIR78		SG30		SSCIR92		SSCIR83	
		SSCIR256	*			SSCIR51	

All were applied in the disequilibrium study,whereas those involved in the diversity study are indicated with an *.

Statistical analysis

For all probe/enzyme combination, each RFLP band found over the sample considered was scored as 1 for presence and 0 for absence. The scoring was entered onto an Excel spread sheet. This binary matrix was used for the computation of the different analyses.

Multivariate analysis

The diversity within the material surveyed was visualised through different factor analyses of correspondences (FAC) (ADDAD 1985). FACs were performed on the binary matrix after disjunction of the variables (markers) in order to give the same weight to the different clones. This factorial analysis treats qualitative data; several independent axes are identified that sequentially account for the largest part of the remaining variation. These axes are linear combinations of the markers, and each clone can be located along them. The loading of the markers on the axes measure the discriminative power of these markers. Markers which are very rare (i.e. frequency below 5%) or very frequent (i.e. frequency over 95%) were not taken as active variables in order not to unbalance the analysis. It is also possible to locate 'inactive' individuals along these axes by calculating their co-ordinates *a posteriori*. In this case, markers specific to the inactive individuals are also considered as inactive variables.

Linkage disequilibrium

Each polymorphic marker found over the cultivars considered for this study is expected to mark as unambiguously as possible the allelic molecular sequences borne by the original founders of these cultivars. These sequences – termed here as 'alleles'- are in discrete number given the bottleneck described in the introduction.

Linkage disequilibrium was tested between the various loci analysed using the Fisher exact test (Mehta and Patel 1983; SAS Institute Inc. 1990, FREQ procedure). The test was performed systematically with all polymorphic markers identified. The analysis consists of testing, at a chosen significant threshold, the hypothesis of independent distribution between two markers. The significance threshold over which the independence hypothesis was refuted was 5%. However, as more than one comparison was tested, the threshold was modified by dividing 5% by the number of comparisons performed in order to discard random associations.

In a first step, markers yielded by all probes were analysed together in order to test whether the associated markers derived preferentially from loci residing on the same linkage group. In a second step, the objective was to consider each linkage group separately and test whether strong bilocus associations appeared more often with closely linked loci.

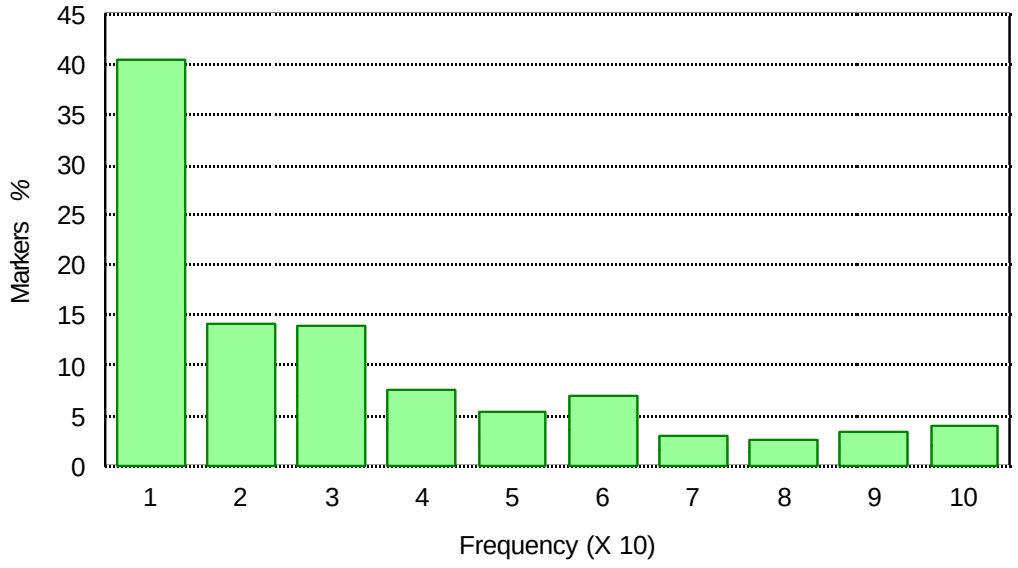
The *S. officinarum* or *S. spontaneum* origin of some of the alleles in disequilibrium was roughly identified. In the first part of this study the *S. officinarum* component of cultivars genome was investigated and data are available for 12 out of the 38 probes used. For the 12 probes each marker in the cultivar present in at least two *S. officinarum* clones was considered as a *S. officinarum* marker, otherwise it was considered as a *S. spontaneum* marker.

RESULTS

Global diversity

For the diversity analysis at the population level, the RFLPs were revealed using 12 probes, each in combination with one or two restriction enzymes. Each probe/enzyme combination revealed between 8 and 40 restriction fragments within the population analysed. A complete set of data was obtained for 21 probe/enzyme combinations, out of a possible 24, applied to both *S. officinarum* clones and cultivars, revealing 13 monomorphic and 386 polymorphic markers. This low number of monomorphic markers was also observed when *S. officinarum* clones and cultivars were considered separately. The frequency of the markers identified in the whole population was calculated (**Figure 1**).

Figure 1 Frequency distribution of the 399 markers revealed with the probe enzyme combinations among cultivars and S.Officinarum clones



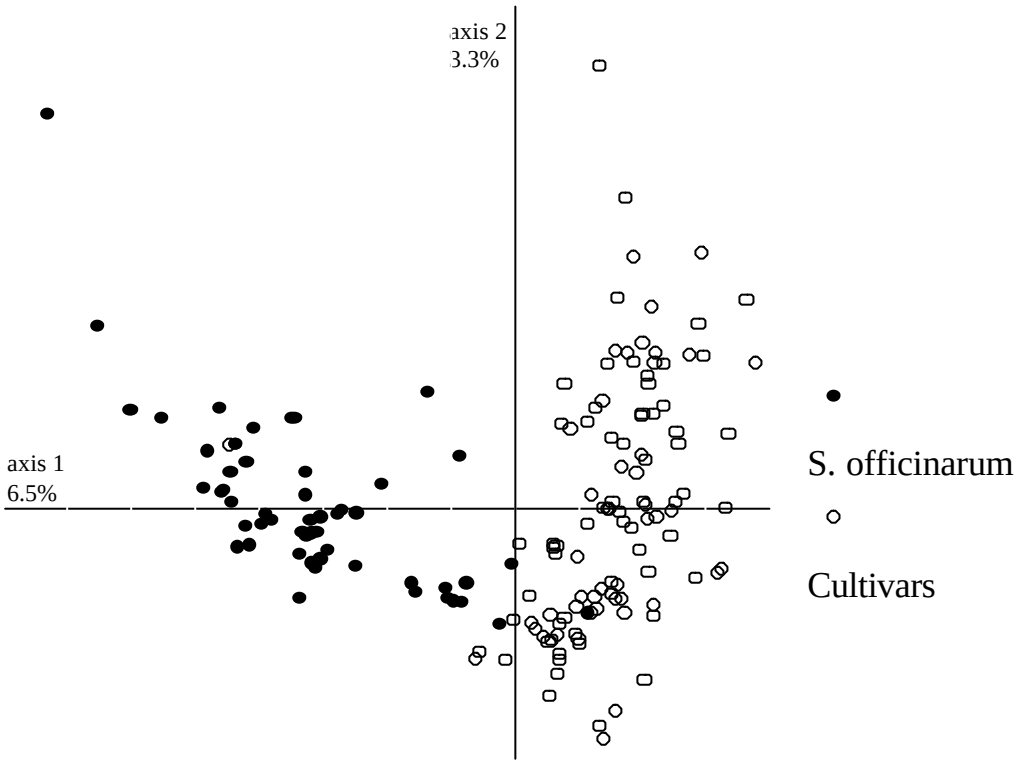
Their distribution in each frequency class between 0.1 and 1 was not homogeneous: 27% of the markers were present in less than eight individuals (5% of the population) and 68% were present in 48 individuals, corresponding to less than one third of the population under survey. This high proportion of rare markers illustrates a large genetic diversity among the material analysed.

Factorial analysis of correspondences (FAC)

Several FACs were performed in order to give a global view of the structure existing within the population under study. A FAC enables also selection of a subsample as a reference ('active individuals') to analyse particular aspects of the structure. The rest of the samples ('inactive individuals') can be located in relation to this reference.

Three FACs were performed on the 160 clones: (1) on the whole sample, (2) taking only reference *S. officinarum* clones as active individuals, and finally (3) taking only cultivars as active individuals.
The first FAC was carried out on 280 active markers and using all 160 clones as active individuals (**Figure 2**).

Figure 2 First plane of a factor analysis of correspondences (FAC) among 51 *S. officinarum* clones and 109 cultivars using 280 active markers.



The first plane explained 9.8% of the variability. This apparently low percentage is likely to be related to the large number of markers employed. *S. officinarum* clones were separated from the cultivars on the first axis with, however, no clear cut delimitation between the two groups. This separation between *S. officinarum* on one side and cultivars on the other side is in agreement with the proportion of markers shared by both groups: 67% of the markers were common to both groups, 27% were present in the cultivars and may therefore correspond to markers specific to *S. spontaneum* and 11% were specific to the *S. officinarum* clones (**Table 3**).

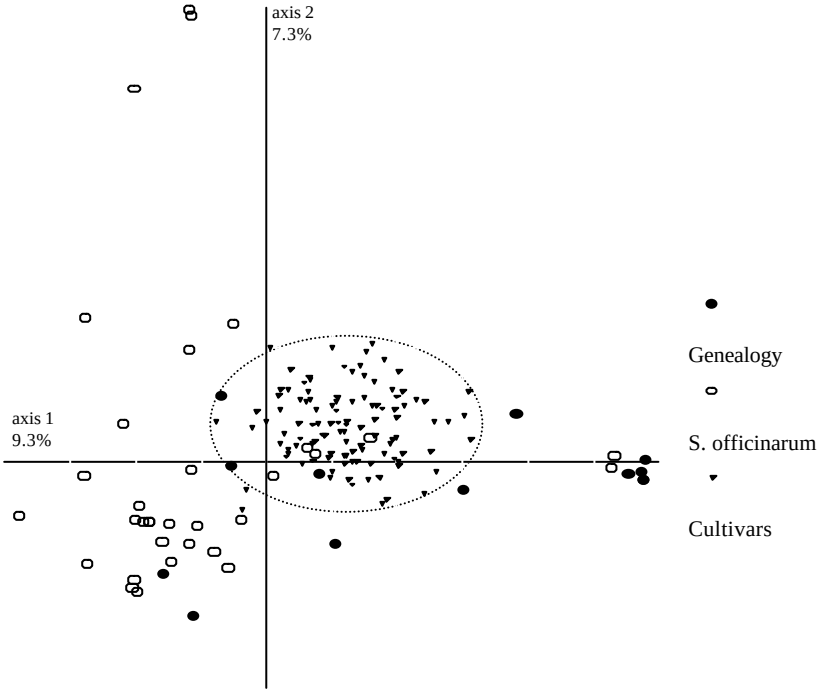
A second FAC was performed using *S. officinarum* as active, and the cultivars as inactive, individuals. This analysis was done in order (1) to visualise how *S. officinarum* clones involved in the genealogy of cultivars are structured compared to those from the area of origin and (2) to evaluate the proportion of the diversity within this species which has been exploited in breeding programs. The first plane of the FAC performed on 220 active markers explained 16.6% of the variation (**Figure 3**).

Table 3 Distribution of markers in the material surveyed

Materials	No. of clones	% Markers
S. officinarum	51	100
Genealogy	12	67
Cultivars	109	100
Mauritius	39	90
Barbados	35	86
Reunion	7	67
Australia	8	66
Others	9	72
First hybrids	11	77
whole sample	160	100
S. officinarum	51	73
		11a
Cultivars	109	89
		27a
		85b

[a] percentage of markers specific to Saccharum officinarum clones or to cultivars
[b] percentage of markers specific to Saccharum officinarum markers in the cultivars

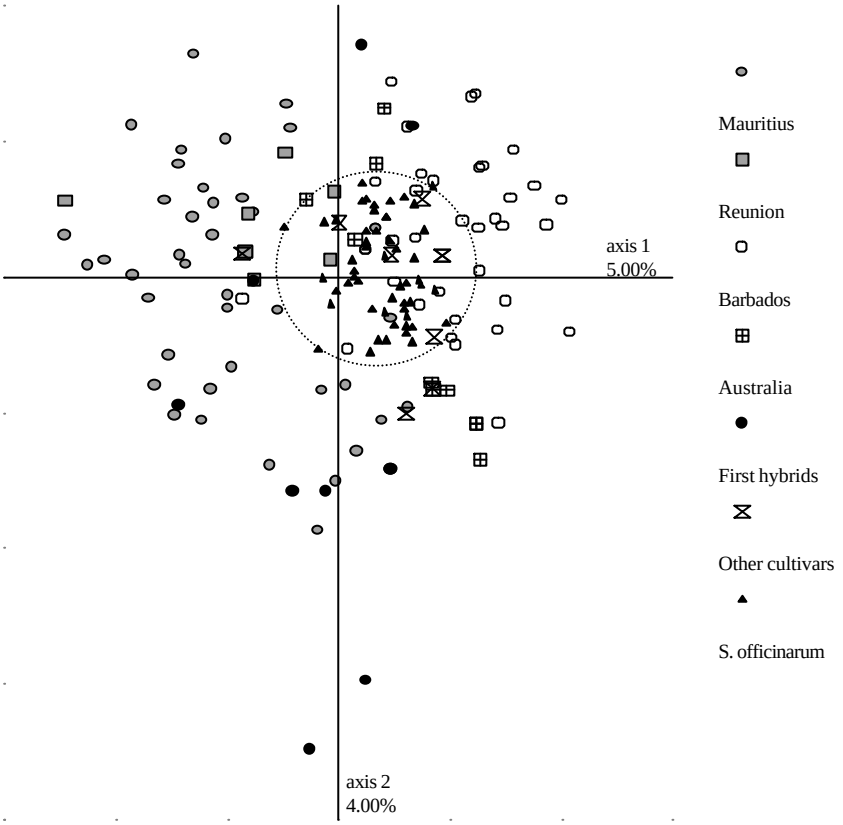
Figure 3 First plane of a factor analysis of correspondences (FAC) among 51 *S. officinarum* clones using 220 active markers, and projection of 109 cultivars as inactive individuals.



No particular structure was observed among the clones. The majority was spread along axis 1. Only three clones were located on the right part of axis 2. The clones involved in the genealogy of cultivars formed a subgroup representative of the diversity present within the majority of the *S. officinarum* clones. This was supported by the proportion of markers shared by them: 67% of the markers present in *S officinarum* were also present in the few clones involved in the genealogy (**Table 3**). Cultivars projected as inactive individuals formed a large cluster near the centre of the first plane. Some *S. officinarum* clones were placed near the cultivars, most of them being involved in the genealogy of cultivars.

Conversely, a third FAC was performed taking only the cultivars as active individuals and the *S .officinarum* clones as inactive in order to evaluate the extent to which the diversity of *S.officinarum* has influenced the diversity among the cultivars (**Figure 4**).

Figure 4 First plane of a factor analysis of correspondences (FAC) among 109 cultivars using 235 active markers and projection of 51 *S. officinarum* clones as inactive individuals



The first plane accounted for 9% of the variability with the 235 active markers used. All the cultivars were homogeneously spread on the first plane. A striking structure, related to the origin of the cultivars was observed: the Mauritian cultivars were on the left half of the plane whereas those from Barbados were on the right half. Clones from Reunion Island and most of the first interspecific hybrids showed similarity to Mauritian cultivars, whereas those from Australia, Guadeloupe, Brazil and South Africa were closer to Barbadan cultivars. The most discriminative markers between Mauritian and Barbadan cultivars were identified using their loading on the first axis of the FAC. Thirteen markers were involved: 10 were either specific or highly frequent in Mauritian cultivars (present in more than 40% of the cultivars) while three were predominant in Barbadan cultivars (present in more than 50%). These markers were scattered on all the linkage groups except for linkage groups 1 and 9 of the cultivar 'R570' map (Grivet et al. 1996). Most of them were absent in the *S. officinarum* clones surveyed here.

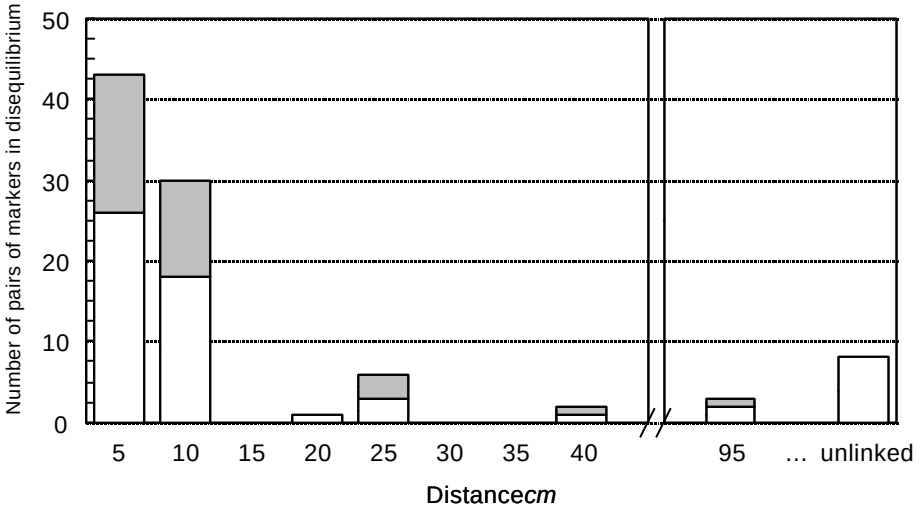
They were therefore considered as being specific to *S. spontaneum.* This low number of markers differentiating the cultivars from different breeding stations is supported by the high proportion of markers present in both groups (**Table 3**): 85% of the markers were present in both Mauritian and Barbadan cultivars. The same trend was observed between cultivars from other breeding stations (**Table 3**). The *S. officinarum* clones, when projected as inactive individuals, were clustered in the centre of the distribution of the cultivars.

LINKAGE DISEQUILIBRIUM

The organisation of the diversity at the chromosome level was analysed through the investigation of the presence of linkage disequilibrium within a subset of 59 homogeneous cultivars chosen from the previous analysis. These cultivars encompassed mainly clones from Mauritius. A few clones from Barbados, Australia, Hawaii, Taiwan, and some of the first interspecific hybrids were also included.
A complete set of data was obtained for 72 RFLP probe/enzyme combinations revealing 1057 polymorphic markers. A total number of 540,688 2x2 Fisher exact tests was performed corresponding to all possible 2x2 comparisons of polymorphic markers revealed by the different probes. A total of 59 cases of significant association was recorded, depicting disequilibrium in the population analysed. Fifty-one of them involved couples of loci which were physically linked on the map of cultivar R570. These loci were scattered over all the sugarcane genome. In the other 8 cases, the markers in disequilibrium corresponded to loci mapped on different linkage groups, excluding physical linkage as an explanation.

The data were then analysed separately for each linkage. Eighty-five linkage disequilibria involving two distinct probes were recorded, 34 of them had not been observed in the first step analysis. Most of them involved tightly linked loci (**Figure 5**).

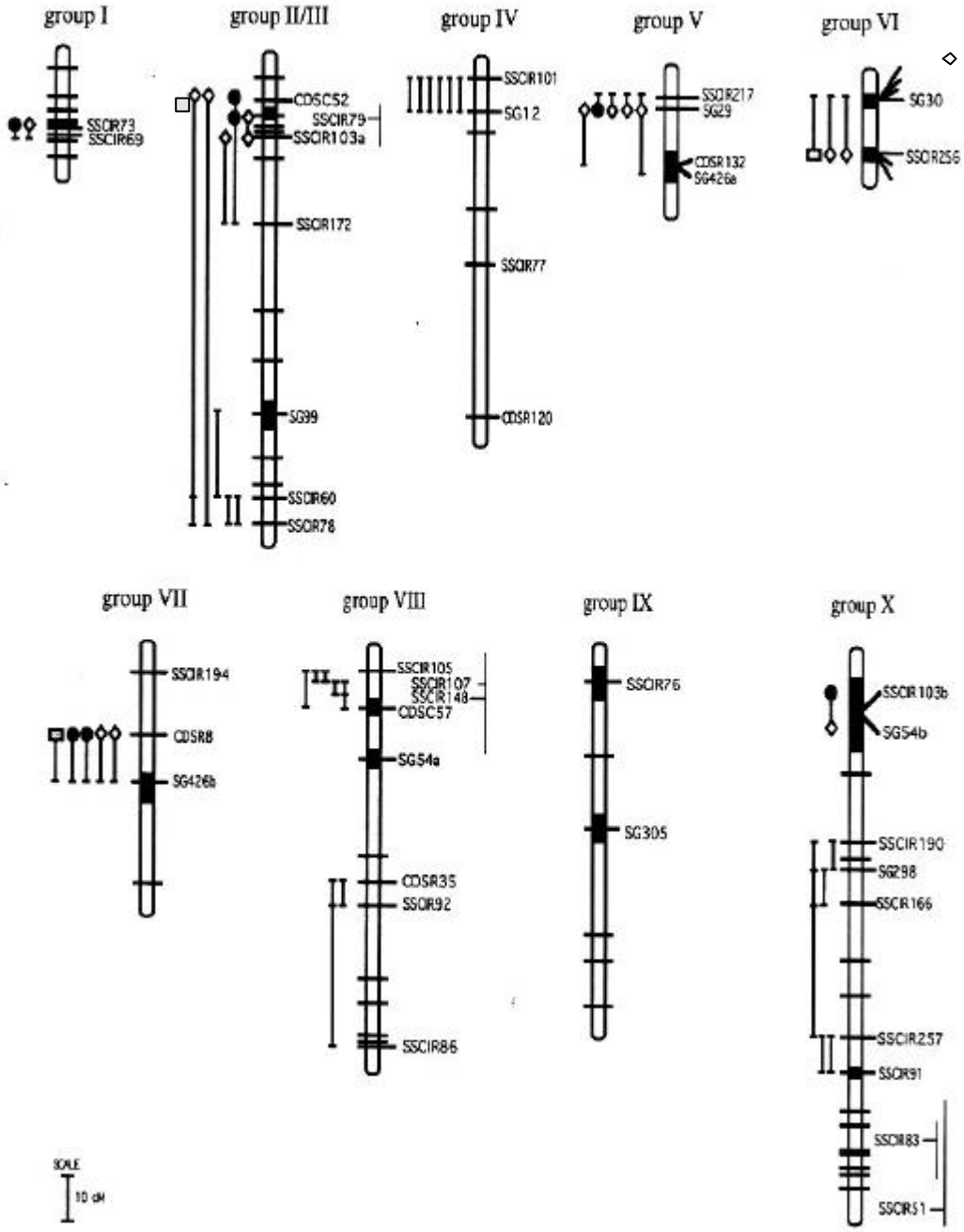
Figure 5 Distribution of the number of associated pairs of markers according to the distance.



Plain bars correspond to associations detected in global analysis and in grey additional associations when only markers of the same linkage group were analysed

After analysis of tri- and tetra-marker associations, the 85 original pairs of cosegregating markers were reduced to 42 different groups involving 33 loci scattered over all the sugarcane genome (Figure 6). Six of them involved alleles at more than two loci, five groups implicated three loci and one group four. Eighty percent of the disequilibrium concerned loci which were distant to less than 10 cM. A few disequilibria were also observed between loci separated by up to 90 cM. All the associations observed within the whole sample corresponded to markers present in at least one of the old cultivars used as progenitors in the breeding program in Mauritius. The specific origin of 24 alleles involved in some disequilibrium could be examined. Fifteen alleles were likely to be derived from *S. spontaneum*, and only seven were from *S. officinarum.* In two cases there was ambiguity (**Figure 6**).

Figure 6 Linkage disequilibrium detected among 59 cultivars and represented along the composite map of R570 (Grivet et al. 1996).



The 38 probes used, corresponding to 41 loci, are shown on the map. When probes are duplicated, each locus is identified by a letter, a or b. Uncertain positions of isolated loci are indicated by a 'T' bar on the right of the linkage group. Uncertain orders of clustered loci are denoted in bold. Loci between which linkage disequilibria were observed are indicated by a bar on the left of the linkage group. Different bars between the loci indicate that several alleles at these loci are in disequilibrium. The origin of the alleles are indicated when known: (•) for *S. officinarum*, ( ) for *S. spontaneum* and ( ) when the origin was ambiguous

DISCUSSION

Our study revealed a large degree of RFLP polymorphisms within the material under survey: only 4% of the markers being monomorphic. This large amount of molecular variation allowed a thorough analysis of the organisation of genetic diversity within *S. officinarum* and the cultivars studied.

Considering *S. officinarum* germplasm, the low number of monomorphic markers identified and the large distribution of the clones on the first plane of the FAC (**Figure 3**) suggest that a considerable diversity exists within this species. This result is in contrast with earlier studies based on isozymes (Glaszmann et al. 1989) and nuclear data (Glaszmann et al. 1990; Burnquist et al. 1992; Lu et al. 1994 a) where a limited diversity was observed. This is probably due to the relatively low number of accessions previously studied. Our data are however congruent with the large morphological diversity observed within *S. officinarum*, even for traits considered diagnostic for this species, such as stalk thickness and leaf width (Artschwager and Brandes 1958; Jagathesan et al. 1970) as well as sugar content (Roach 1965; Nair et al. 1980). Although only a few *S. officinarum* clones were involved in the genealogy of cultivars, they clearly represent the diversity within *S. officinarum* from the area of origin. This could be related to the high ploidy and heterozygosity level in sugarcane as illustrated by the large number of bands revealed with single copy probes.

The genome of cultivars consists of approximately 80% of *S. officinarum* chromosomes. This is also illustrated by our data. Knowing that the similarity between *S. officinarum* and *S. spontaneum* is relatively low (20%, Lu et al. 1994 a), most of the markers present in the cultivars and *S. officinarum* clones were probably inherited from *S. officinarum*. The high proportion of markers shared by *S. officinarum* and the cultivars illustrates the effect of the nobilisation process. The joint analysis of the cultivars and the *S. officinarum* clones shows that in general the cultivars have retained most alleles from the *S. officinarum* under survey, although relatively few *S. officinarum* clones are reported in the genealogy of cultivars. It is probably due to the high ploidy of sugarcane and to the fact that a few other noble clones have also been introduced in breeding programs to a lesser extent.

The differentiation observed between the cultivars from different breeding stations is surprising knowing the tradition of profuse exchange of parental material between sugarcane breeding stations. This difference is explained by few markers, most of them being specific to or predominant in Mauritian cultivars. The majority of these markers are specific to *S. spontaneum*, suggesting that the main structuring part of the variability among the cultivars is due to alleles inherited from *S. spontaneum*. In both selection stations, MSIRI in Mauritius and WICSCBS in Barbados, as in other stations, almost the same genetic pool has been initially used to create cultivars, thus explaining a relatively low degree of differentiation. However, the first interspecific hybrids created in India are found to be closer to the Mauritian cultivars. A thorough observation of the genealogy shows the frequent occurrence of locally produced hybrids as great grandparents and grandparents in Barbados. In contrast, in Mauritius the first hybrids created in India have been used as parents in a recurrent fashion (Ramdoyal pers. comm.), thus explaining the greater affinity of the first Indian cultivars to Mauritian ones. This recurrent use of early generation interspecific hybrids in the Mauritian breeding program could have resulted in cultivars having more *S. spontaneum* markers which would account for the distinction between cultivars of different origins.

Our study offers a basis for reasoning the management of the genetic diversity in sugarcane cultivars. The restricted number of *S. officinarum* clones that contributed to cultivars is a common matter of concern. The large number of bands revealed with single copy probes is indicative of a high level of heterozygosity, which can generate considerable genotypic diversity in this polyploid background. Therefore, although few, the main noble clones used in early history of modern sugarcane breeding provided a template with large potential for the recombination work by breeders. The sample surveyed revealed that even though 73% of the markers were present in *S. officinarum*, only 11% were specific as compared to cultivars. This 11% of markers illustrate an additional reservoir to widen genetic diversity in cultivars and represent 15% of *S. officinarum* diversity.

The present work reveals a diversity higher than expected within *S. officinarum*, probably due to the combination of the high number of individuals analysed and the investigation of the large portion of the genome. Most of this diversity is present in the cultivars. However, for the unexplored part, molecular markers can provide a guide for further broadening the genetic base of the cultivars with *S. officinarum*, especially if we are focussing on sugar improvement.

A striking structure was also revealed among the cultivars according to their origin. The other main component of cultivars diversity corresponds to the *S. spontaneum* genome fraction. Our results illustrate the large genetic contribution of this species and provide indications that it may be related to the specialisation of the cultivars. Since this portion of the genome of cultivars is less redundant and may have contributed to many favourable traits, it is more amenable to QTL analysis and further marker-assisted selection.

After analysing the diversity at the population level, we focussed on the organisation of this diversity at the chromosome level. The aim of this part was to test whether the breeding history of sugarcane has installed a general linkage disequilibrium still perceptible today.

The material under survey was chosen from the first study to represent a homogeneous set of commercially cultivated clones in order to detect association that are due only to genetic linkages.
Many instances of disequilibrium were uncovered, although only two restriction enzymes were used in combination with each probe.

This is relatively low to identify all the alleles for a high polyploid and heterozygous species as sugarcane. The disequilibrium identified involved loci scattered over the sugarcane genome. Associations between physically linked loci are a reality in this sample and their detection might be refined in the future.

All the marker combinations in disequilibrium were present in at least one of the first interspecific hybrids included in this study, thus pointing at the likely donors of the chromosome segments that bear the markers. The loci involved are generally separated by less than 10 cM on the reference genetic map. The few associations between distantly linked or unlinked loci may correspond partly to escapes through the statistical screening for significance and partly to associations derived from the recurrent use of the first Indian interspecific hybrids in the breeding program in Mauritius. The whole Figure gives an indication that 10 cM is the approximate genetic size of the chromosome segments that can be marked throughout the genealogy of modern cultivars.

It is noteworthy that two thirds of the alleles involved in disequilibrium (and whose origin was determined) were derived from *S. spontaneum*, although only about 20% of the genome in cultivars is inherited from this species. This is probably related to the higher resolution of molecular markers on the part of the genome that is both less represented and more polymorphic (Lu et al, 1994a), thus less prone to marker ambiguity.

The scope of application of our findings resides essentially in the possibility of tracking alleles at QTL in different cultivars once the associated markers have been identified. It will also be interesting to specifically intensify the study of molecular diversity in the vicinity of loci where some QTL of interest have been shown to reside. A survey of cultivars with several probes mapped in such a region in combination with a high number of restriction enzymes may have a high-resolution power. Many alleles may be revealed for each locus and may give access to most or all the multilocus haplotypes present in the few ancestral clones at the origin of modern cultivars. There may be opportunities to relate this molecular diversity to the variation scored for traits of value for plant breeders and sugarcane growers.

REFERENCES

ADDAD. 1985. *Manuel de référence*. Association pour le Développement et la Diffusion de l'Analyse des Données, Paris. pp 198.

ARCENEAUX G. 1967. Cultivated sugarcanes of the world and their botanical derivation. *Proc Int Soc Sugarcane Technol* 12: 844-854.

ARTSCHWAGER E, BRANDES EW. 1958. *Sugarcane (Saccharum officinarum), origin, charactristics and descriptions of representative clones*. USDA Agriculture Handbook n°122, Washington.

BREMER G. 1930. The cytology of *Saccharum*. *Proc Int Soc Sugar Cane Technol* 3: 408-415.

BURNQUIST WL, SORRELLS ME, TANKSLEY S. 1992. Characterization of genetic variability in *Saccharum* germplasm by means of restriction fragment length polymorphism (RFLP) analysis. XXI *Proc Int Soc Sugar Cane Technol* 2: 355-365.

DA SILVA JAG, SORRELLS ME, BURNQUIST WL, TANKSLEY SD. 1993. RFLP linkage map and genome analysis of *Saccharum spontaneum*. *Genome* 36: 782-791.

GLASZMANN JC, FAUTRET A, NOYER JL, FELDMANN P, LANAUD C. 1989. Biochemical genetic markers in sugarcane. *Theor Appl Genet* 78: 537-543.

GLASZMANN JC, LU YH, LANAUD C. 1990. Variation of nuclear ribosomal DNA in sugarcane. *Jour Genet and Breed* 44: 191-198.

GRIVET L, D'HONT A, ROQUES D, FELDMANN P, LANAUD C, GLASZMANN JC. 1996. RFLP mapping in cultivated Sugarcane (*Saccharum* spp.): Genome organization in a high Polyploid and Aneuploid interspecific hybrid. *Genetics* 142: 987-1000.

HOISINGTON D. 1992. *Laboratory protocols*. *CIMMYT* Applied Molecular Genetics Laboratory, Mexico, DF CIMMYT.

JAGATHESAN D, SREENIVASAN TV, RATNAMBAL MJ. 1970. Chromosome numbers in noble sugarcanes. *Indian Jour Hered* 2: 89-96.

LI HW, PRICE S. 1967. Chromosome numbers of noble sugarcane clones. *Proc Int Soc Sugar Cane Technol* 12: 884-886.

LU YH, D'HONT A, PAULET F, GRIVET L, ARNAUD M, GLASZMANN JC. 1994b. Molecular diversity and genome structure in modern sugarcane varieties. *Euphytica* 78: 217-226.

LU YH, D'HONT A, WALKER DIT, RAO PS. 1994a. Relationships among ancestral species of sugarcane revealed with RFLP using single copy maize nuclear probes. *Euphytica* 78: 7-18.

METHA CR and PATEL NR. 1983. A network algorithm for performing Fisher's exact test in rxc contingency tables. *J Amer Statist Ass* 78: 427-434.

NAIR NV, SOMARAJAN KG, BALASUNDARAM N. 1980. Genetic variability, heritability and genetic advance in *Saccharum officinarum* L. *Int Sugar Jour* 82: 275-276.

PRICE S. 1957. Cytological studies in *Saccharum* and allied genera, III. Chromosome numbers in interspecific hybrids. *Bot Gaz* 118: 146-159.

PRICE S, DANIELS J. 1968. Cytology of south Pacific sugarcane and related grasses; with special reference to Fiji. *Jour Heredity* 59: 141-145.

ROACH BT. 1965. Sucrose of noble canes. *Sugarcane Breed Newsl* 15: 2.

ROACH BT. 1969. Cytological studies in *Saccharum*. Chromosome transmission in interspecific and intergeneric crosses. *Proc Int Soc Sugar Cane Technol* 13: 901-920.

ROACH BT. 1972. Nobilisation of sugarcane. *Proc Int Soc Sugar Cane Technol* 14: 206-216.

SAS INSTITUTE INC. 1990. *SAS procedures guide*, version 6, third edition. SAS Institute Inc,Cary, NC, USA, 705 p.

SREENIVASAN TV, AHLOOWALIA BS, HEINZ DJ. 1987. Cytogenetics. *In* HEINZ DJ .ed. *Sugarcane improvement through breeding*. Elsevier, Amsterdam. pp 211-253.

RELATIONSHIP BETWEEN CANOPY COVER AND LIGHT INTERCEPTION IN POTATO IN A TROPICAL CLIMATE

Y Cadersa* and *N Govinden

Agricultural Research and Extension Unit.

ABSTRACT

Four field experiments were conducted in the two potato planting seasons to determine the relationship between canopy cover and light interception. Results indicated that canopy cover and light interception were higher in tropical than in temperate clones, and in interrows of sugar cane, canopy cover of some clones exceeded 100%. A close and linear relationship was obtained between % canopy cover and % light interception until maximum canopy cover but regression coefficients were different between cropping systems, clones and intra row spacings at individual sites. Canopy cover using a grid can be used to measure light interception, but the relationship must be calibrated for clones with different canopy characteristics, cropping systems and even sites.

Keywords: potatoes, cropping systems, canopy cover, light interception, potato clones, regression coefficients

INTRODUCTION

The total biological production of plants is directly related to the amount of light intercepted by the foliage (Monteith 1977). One of the ways of assessing the performance of crops is to measure the amount of light intercepted by the crop and to calculate the efficiency with which it is converted into dry matter (Allen and Scott 1980; Russell and Ellis 1988). The proportion of intercepted radiation may be measured with radiation instruments such as tube solarimeters and linear ceptometers. This method is not destructive, but the instruments are costly. Moreover, the sensors record light intercepted by green as well as non- green leaves and consequently, they overestimate interception when the crop starts senescing. A simple and cheaper alternative to the use of sensors is to estimate light interception from canopy cover measurement. There are different methods for measuring canopy cover such as overhead photography (Steven et al. 1986), but one of the simplest is through the use of a grid (Borstal and Harris 1983). The grid method is quick; hence sampling can be done thoroughly and frequently. Its major advantage is that it can discriminate between green and non -green leaves. A strong and linear correspondence has been observed between canopy cover and light interception in some crops, such as field beans and sugar beet (Steven et al.1986). In potato, under temperate conditions, a linear and close relationship was obtained between percentage canopy cover and percentage light interception (Fahem and Haverkort 1988). However, similar data on potato are limited under tropical conditions where moreover, potato is often produced as an intercrop. For instance, in Mauritius, 79% of the potato is produced as an intercrop of sugar cane. The objective of this present work was to determine the precision with which light interception can be estimated from canopy cover in potato. By growing clones of temperate and tropical origins in two seasons at different plant densities and in two cropping systems, pure stand and intercropping with sugar cane, the study sought to establish the usefulness of the relationship between canopy cover and light interception under a range of conditions.

MATERIALS AND METHODS

Four trials were planted in Mauritius (20°S latitude, 57°E longitude) in 1997; two in the first season (May-June plantation) at Réduit and Union Park Experimental Stations and two in the second season (August-September plantation) at Highlands and Union Sugar Estates. Mean temperatures in the first season varied from a minimum of 15.3°C to a maximum of 22.4°C while in the second season,

minimum temperature averaged18°C and maximum temperature never exceeded 31°C. Details of trials and site conditions are presented in **Table 1**.

Table 1 Details of trials planted in 1997.

Site	**Reduit 2**	**Highlands**	**Union Park 1**	**Union**
Altitude (*m*)	305	450	350	53
Climatic zone	Humid	Super humid	Super humid	Humid
Soil type	Low Humic Latosol	Humic Ferruginous Latosol	Latosolic Brown Forest.	Low Humic Latosol
Soil Analysis:				
pH	6.0	5.4	6.5	5.9
P (*ppm*)	114	78	238	119
K (*me%*)	0.64	0.30	0.81	1.10
Si (*ppm*)	603	890	2355	335
Irrigation (*mm*)	300	Nil	Nil	276
Total seasonal rainfall (*mm*)	163.1	333.8	626.5	150.2
Mean Temp. *°C*	Min Max	Min Max	Min Max	Min Max
	Jun 16.0 23.4	Sept 14.7 22.4	Jun 14.9 22.3	Sept 20.1 28.2
	Jul 16.0 22.4	Oct 15.3 23.1	Jul 14.9 20.6	Oct 20.3 29.2
	Aug 15.2 23.0	Nov 17.5 26.3	Aug 14.9 22.5	Nov 20.4 30.5
Design	Rand Complete Block	Rand Complete Block	Split plot	Split plot
Replicates	4	4	3	3
Sugarcane Varieties				
Variety	M 3035/66	M 3035/66	M 1658/78	M 695/69
Date Plantd	10-May-97	14-Aug-97	15-May-97	29-Aug-97
Potato clones:				
Temperate:	Spunta	Spunta	Spunta	Spunta
	Stirling	Stirling	84-2	84-2
Tropical:	57-2	57-2	26-2	26-2
	52-2	52-2		
	26-2	26-2		
Date potato planted	17-May-97	18-Aug-97	26-May-97	01-Sep-97
Spatial arrangement of sole potato:				
Number of rows/plot	9	9	5	5
Row length (*m*)	8.4	8.4	7.2	7.2
Spatial arrangement of intercropped potato:				
Potato rows	5	5	5	5
Cane rows	6	6	6	6

There were two sets of two trials, one in each season. In the first set, two temperate clones were compared to three tropical ones whereas in the second set, one temperate clone was compared to two tropical ones. The potato was grown in pure stands as well in interrows of plant sugar cane.

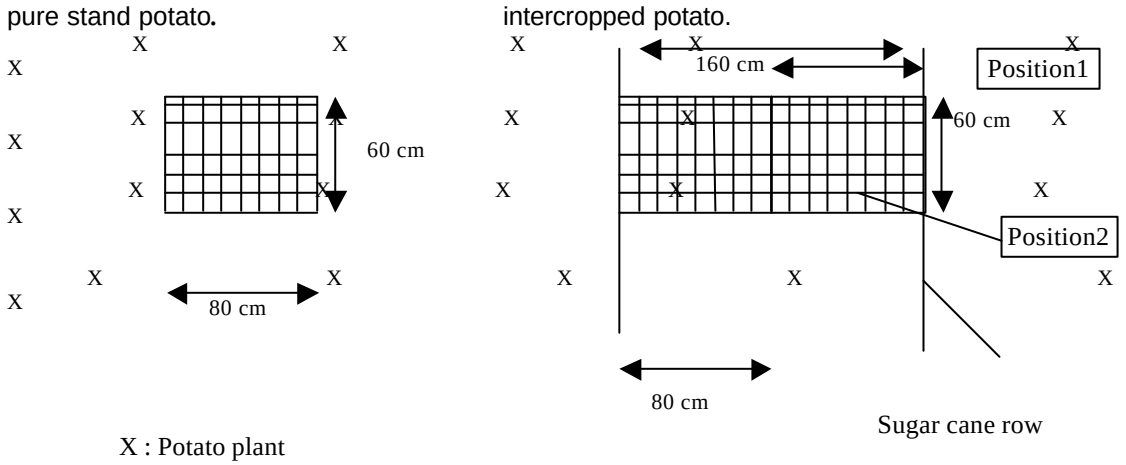
Land was prepared with a disc plough followed by a rotovator. Cane furrows 30-40 cm deep and wide were made with a pneumatic tractor at 160 cm intervals. After cane plantation, potato furrows were made between cane rows. Pre germinated seed tubers were planted at 30 cm within each potato row in the first set of trials at Réduit and Highlands whereas in the second set at Union and Union Park, density was varied by planting at intra row spacings of 24, 30 and 40 cm.

At Réduit and Highlands, the temperate clones were Spunta and Stirling originating from the Netherlands and the tropical clones were 57-2, 52-2 and 26-2 originating from MSIRI's breeding programme. At Union and Union Park, Spunta was the only temperate clone used and the tropical clones were 84-2 and 26-2 (**Table 1**).

Fertilizers were applied at recommended rates(MSIRI,1991; MSIRI,1995) based on soil analysis. At Réduit, Highlands and Union, 1538 kg ha^{-1} of the complex fertiliser 13:13:20:2 (N,P_2O_5,K_2O,MgO) were applied to sole potato and 769 kg ha^{-1} to the intercrop at planting. A mixture of 385 kg ha^{-1} 13:13:20(N, P_2O_5,K_2O) and 192 kg ha^{-1} Calcium Ammonium Nitrate (26% N) was applied to sole potato and half the rate to the intercrop at Union Park. For sugar cane, 17:8:25(N, P_2O_5,K_2O) was applied at 550 kg ha^{-1} at all locations. Weeds, fungi and insects were controlled by spraying with chemicals at the recommended rate by Govinden et al. (1986)

The proportion of ground covered with green leaves was measured weekly using a grid. It consisted of a wooden frame divided into 100 equal sections of dimensions 80 cm x 60 cm- a multiple of the planting pattern for potato. The grid was placed on top of the potato at one metre from the ground and only those sections more than half filled with green leaves were counted by observing vertically above to avoid parallax error. In sole potato, the grid was placed half way on each side of the potato row to sample two plants(**Figure 1**). In intercropped potato, two grid positions were used, one on either side of the potato row since in some potato clones, branches extend beyond 80 cm on either side of the row(**Figure 1**). Two measurements were made per plot.

Figure 1 Placement of wooden grid for the measurement of canopy cover in:



Photosynthetically active radiation (IPAR) in the range of 400-700nm intercepted by the canopy was measured with a linear Accu PAR ceptometer(Decagon Devices, Washington, U.S.A) . IPAR was recorded once weekly above and below the canopy at random positions. Reflectance in the PAR range was ignored since it may be considered to be relatively constant and low (Scott et al. 1968). A total of 40 readings were taken per plot; this sample having been shown in preliminary tests to produce a coefficient of variation below 5%. In order to minimize the influence of solar heights, all readings were taken between 10h30 and 15h00.

Analysis of variance was performed on data on canopy cover and intercepted radiation and treatments were compared using the Least Significant Difference (LSD) test.

Regression analysis was also performed to determine the relationships between percentage canopy cover and percentage light interception for different clones, cropping systems and planting densities. The homogenity of regression coefficients was tested by the ANOVA method described by Gomez and Gomez (1983).

RESULTS AND DISCUSSION

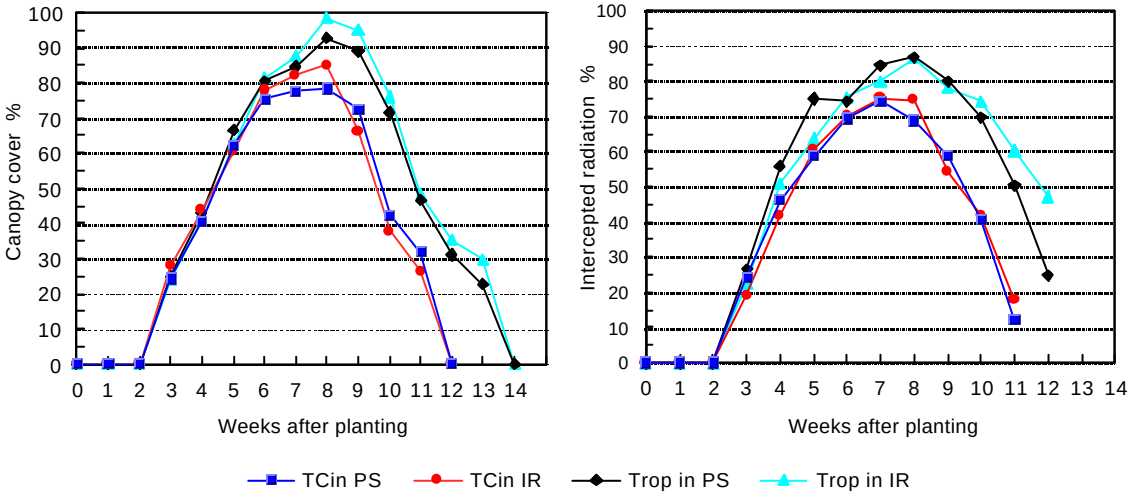
Canopy cover and light interception

The general trend in canopy cover and light interception is an increase as from three weeks after planting to reach maximum values at 7 to 9 weeks and a decline thereafter as senescence sets in.

Clones effects

Canopy cover and light interception were significantly higher in tropical clones than in temperate clones (**Figures2 and 3**) due in part to differences in maturity. This in conformity with the findings of Demagante et al. 1996) who found that tropical clones tuberise later and thus had more developed canopies of longer durations whereas early maturing clones develop smaller canopies of shorter durations.

Figure 2 Canopy cover and intercepted radiation in temperate and tropical potato clones in pure stand (p.s) and in interrows of sugarcane (IR) Mean of Réduit and Highlands



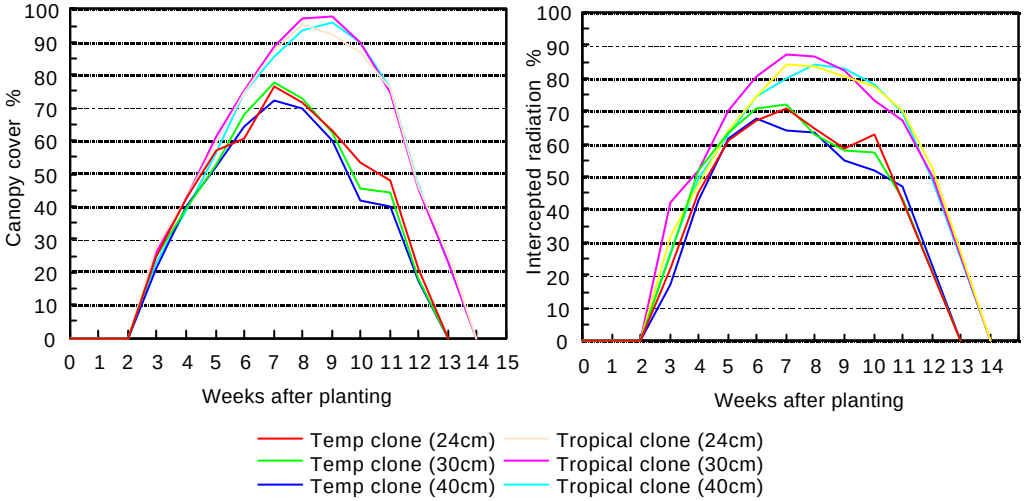
CROPPING SYSTEMS EFFECTS

In pure stand, peak canopy cover reached 100% while in intercropping, it exceeded 100% and reached 120% in clones 57-2 and Stirling(data not presented). In pure stand, potato plants compete for growth resources such as light and nutrients because of limited space. At canopy closure, the 80cm interrow space is completely covered by overlapping leaves from adjacent rows. Thus, space for further haulm growth is restricted, especially in clones which achieve complete ground cover in less than nine weeks and maintain it for a sufficiently long period. In intercropping, potato rows are further apart and the young cane does not make much demand on growth resources available in the interrows (Govinden 1990). Therefore, by benefiting from growth resources and more space available in the interrows, some clones are able to display a larger canopy. At Réduit, in pure stand, the canopy size of Stirling was similar to that of Spunta whereas in intercropping, it was larger, because of its recumbent growth habit.

PLANT DENSITY EFFECTS

At Union and Union Park, when sites and cropping systems were pooled, intra row spacing did not affect light interception (**Figure 3**) and canopy cover in a given clone.

Figure 3 Canopy cover and intercepted radiation at three intra row spacings in a temperate potato clone and in tropical potato cultivation systems (sole and intercropped). (mean of 2 clones). Mean of 2 sites (Union and Union Park) and 2 cropping



Relationship between percentage canopy cover (% C.C) and percentage light interception (% LI)

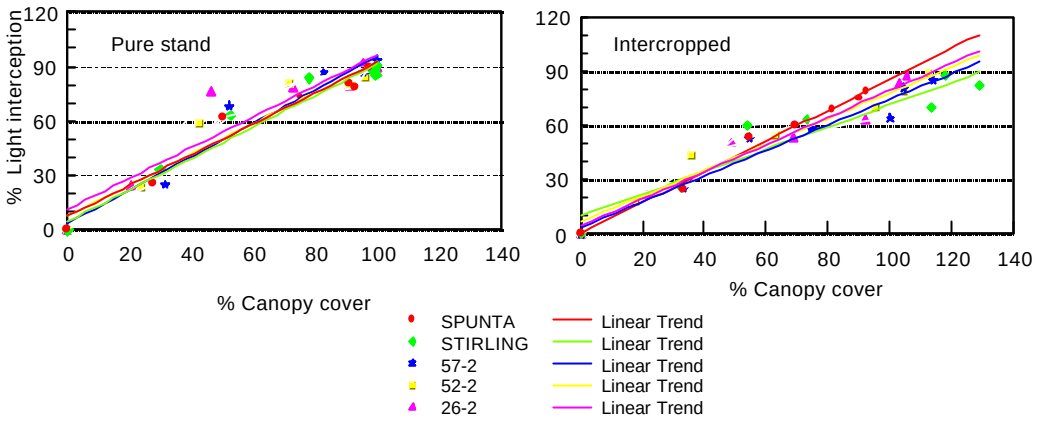
Light interception was compared with canopy cover from the third week after planting until full canopy was reached. Observations made after full canopy when C.C decreased were discarded because during the senescent phase, LI data were unreliable since radiation instruments do not distinguish between green and non-green foliage (Burstall and Harris 1983). Therefore, in this study, in order to verify the precision with which light interception can be estimated from canopy cover, the relationship between the two was examined in the first part of the crop cycle. Results obtained from four trials in 1997 conform to those of Burstall and Harris (1983) and Firman and Allen (1989). A linear relationship was obtained between % C.C and % LI in all clones, in both cropping systems and at all plant densities.

At Highlands, both in pure stand and intercropping, regression coefficients of temperate and tropical clones were homogeneous whereas, on average across clones, regression coefficients were lower in intercropping than in pure stands.

At Réduit, in pure stand, regression coefficients in temperate and tropical clones did not differ significantly while in intercropping, regression coefficients were higher in temperate than in tropical clones.

When sites and cropping systems were pooled, the regression lines of temperate and tropical clones were homogeneous and accounted for more than 95% of the variance (**Figure 4**).Therefore, the use of canopy cover measured with a grid is a valid estimate of light interception obtained from tube solarimeters. This is in accordance with Haverkort et al (1991) who concluded that % C.C is the best estimate of intercepted solar radiation.

Figure 4 The relationship between % canopy cover and % light interception in pure stand (a) and intercropped potato (b) at Réduit



At Union, in pure stand, regression coefficients were not different at the different spacings (**Table 2**).At a given spacing, regression coefficients of 26-2 and 84-2 were not significantly different. In intercropping, regression lines in Spunta and 84-2 were similar. The slope was higher at spacing of 24cm than at 40cm in 26-2. At the closest spacing (24cm) in Spunta, the slope was significantly different from all treatments in 84-2 and from spacing of 30cm and 40cm in 26-2. Regression coefficients were different at closer spacing between 26-2 and 84-2. Between cropping systems, regression lines were similar in Spunta and 26-2.

Table 2 The regression functions for the relationship between % canopy cover and % light interception at Réduit.

Clones	Pure stand potato		Intercropped potato	
	Relationship	r^2 (P< 0.01)	Relationship	r^2 (P< 0.01)
SPUNTA	LI = 0.78 C.C + 11.359	0.91**	LI = 0.84 C.C + 1.161	0.96**
STIRLING	LI = 0.85 C.C + 7.459	0.95**	LI = 0.61 C.C + 9.810	0.89**
57-2	LI = 0.92 C.C + 3.568	0.94**	LI = 0.70 C.C + 3.709	0.95**
52-2	LI = 0.85 C.C + 7.716	0.93**	LI = 0.71 C.C + 6.690	0.96**
26-2	LI = 0.85 C.C + 11.364	0.87**	LI = 0.75 C.C + 4.339	0.96**
All clones	**LI = 0.86 C.C + 6.753**	**0.94****	**LI = 0.72 C.C + 5.017**	**0.96****

At Union Park, the regression lines were homogeneous in intercropped 26-2, 84-2 and sole cropped Spunta. The slopes were higher at spacing of 40 cm in intercropped Spunta and sole cropped 84-2 while in 26-2 in pure stand, a higher regression coefficient was obtained at spacing of 24 cm compared to 30 cm. In Spunta at 40 cm, the regression coefficient was higher than in clones 26-2 and 84-2 at all spacing in interrows. However, there was no difference in treatments between 84-2 and 26-2. In 26-2 and 84-2, regression lines were similar between cropping systems. In intercropping, at spacing of 40cm, a higher regression coefficient was obtained in Spunta than at spacing of 24, 30 and 40cm in pure stand.

In interrows, regression coefficients between treatments were homogeneous at both Union and Union Park. In pure stand, regression coefficients were significantly higher at Union in Spunta at the 3 intra row spacing and in 84-2 at the closer spacing (**Table 3**).It was also observed that the range of regression coefficients between treatments in tropical clones is smaller (0.77- 0.91). This may be ascribed to the fact the clumping of stems in 26-2 and 84-2 may have produced a canopy where diffuse radiation and sunflecks are less able to penetrate.

Table 3 Regression equations for the relationship between % C.C and % LI in three potato clones grown in pure stand and in three intra row spacing at Union (Mean of three clones and two cropping systems)

Intra row spacing (*cm*)	Relationship	r^2(P< 0.01)
24	LI = 0.88 C.C + 5.288	0.97**
30	LI = 0.87 C.C + 8.545	0.95**
40	LI = 0.93 C.C + 4.580	0.98**

When sites and cropping systems were pooled, linear regressions of light interception and canopy cover gave good fits (R^2 > 0.90**) with homogeneous regression coefficients between all spacings in both temperate and tropical clones (**Table 4**).

Table 4 Regression equations for the relationship between % C.C and % LI in three potato clones grown in pure stand and in interrows of sugarcane at Union (Mean of three intra-row spacings)

Clone	PURE STAND		INTERCROPPING	
	Relationship	r^2(P< 0.01)	Relationship	r^2(P< 0.01)
Spunta	LI = 1.07 C.C + 0.709	0.91**	LI = 0.96 C.C + 0.014	0.95**
26-2	LI = 0.85 C.C + 9.347	0.96**	LI = 0.89 C.C + 6.812	0.96**
84-2	LI = 0.96 C.C + 5.879	0.95**	LI = 0.84 C.C + 8.007	0.96**

CONCLUSION

The results of this study demonstrate that under a given clone, site, cropping system, agronomic practice, canopy cover is closely and linearly related to light interception but not in a one to one function. However, at different sites, and under different cropping systems, different clones give different regression coefficients. This means that canopy cover can be used in place of light interception but first the relationship must be calibrated for clones with different canopy characteristics and cropping systems and even sites.

ACKNOWLEDGEMENT:

Thanks are expressed to estate agronomists and field officers of Réduit and Union Park Experiment Stations for allowing field trials to be carried out.

REFERENCES

ALLEN EJ and SCOTT RK. 1980. An analysis of growth of the potato crop. *Journal of Agricultural Science*, Cambridge, 94: 583- 606.

BURSTALL L and HARRIS PM. 1983. The estimation of percentage light interception from leaf area index and percentage ground cover in potatoes. *Journal of Agricultural Science*, Cambridge, 100: 241-244.

DEMAGANTE AL, HARRIS PM and VAN DER ZAAG P. 1996. *Field Crops Res*., 47: 191-204.

FAHEM M and HAVERKORK AJ. 1988. Comparison of the growth of potato crops grown in autumn and spring in North Africa. *Potato Research*, 31: 557-568.

FIRMAN DM and ALLEN EJ. 1988. Relationship between light interception, ground cover and leaf area index in potatoes. *Journal of Agricultural Science*, Cambridge, 113: 355-359.

GOMEZ KA and GOMEZ AA. 1983. *Statistical Procedures for Agricultural Research*. IRRI, Philippines.

GOVINDEN N. 1990. Intercropping sugar cane with potato in Mauritius. A successful cropping system. *Field Crops Research* 25 : 99-110

GOVINDEN N, MC INTYRE G, AUTREY JC and RAJABALEE MA. 1986. *Growing potatoe*s. Advisory bulletin, MSIRI, Réduit.

HAVERKORK AJ, UENK D, VEROUDE H and VAN DE WAART M. 1991. Relationships between ground cover, intercepted radiation, leaf area index and infrared reflectance of potato crops. *Potato Research*, 34: 113-121.

MSIRI *see under* Mauritius Sugar Industry Research Institute

MAURITIUS SUGAR INDUSTRY RESEARCH INSTITUTE. 1991. *Fertilisation requirements of potat*o. Rec. Sheet, Number 58.

MAURITIUS SUGAR INDUSTRY RESEARCH INSTITUTE. 1995. *Fertilisation of plant and ratoon canes*. Rec. Sheet, Number 88.

MONTEITH JL. 1977. Climate and the efficiency of crop production in Britain. *Proc. R. Soc*., Series B, 281:277-294

SCOTT D, MENALDA PH and BROUGHAM RW. 1968. Spectral analysis of radiation transmitted and reflected by different vegetables. *N.Z. J. Bo*t.6: 427-449.

STEVEN MD; BISCOE PV; JAGGARD KW and PARUNTU J. 1986. Foliage cover and radiation interception. *Field Crops Research* 13: 75-87

EFFECTS OF TWO WATER-RETENTIVE CHEMICALS ON SEEDLING SURVIVAL AND YIELD OF TRANSPLANTED TOMATO

M Rughoo* and *N Govinden

Mauritius Sugar Industry Research Institute

ABSTRACT

In a tomato research-planning workshop in 1997, the use of water-retentive chemicals (hydrogels) was identified as a possible solution to minimize the effects of water stress. Nine replicated trials were planted during the summer and winter seasons of 1997 and 1998 in different localities of Mauritius to investigate the effects of two hydro gels at recommended rates on the survival of seedlings after transplantation and on the yield of cooking tomato var. Sirius. Six trials were irrigated and the remaining three were not. Farmyard manure and factory filter muds were also included in the treatments since they are commonly used as amendments in tomato production.

Under irrigation, on average, 87% of the transplanted seedlings survived and the hydrogels had no effect on seedling survival or yield. Though farmyard manure or factory filter muds had no effect onseedling survival, they increased yield by 14 % and 10%, respectively.

Under rainfed conditions, in the absence of the soil amendments, only 11% of tomato seedlings survived and very low yields were obtained. Significantly more seedlings survived when the hydrogels or organic amendments were used. Best results were obtained when a hydrogel was combined with an organic soil amendment. When the amendments were used alone, significantly higher yields were obtained with manure and factory filter muds but not with the hydrogels. It is therefore concluded that under rainfed conditions, organic soil amendments either as manure or factory filter muds are worthwhile whereas the hydrogels are not.

Keywords: tomatoes, *Lycopersicon esculentum*, hydrogels, polymers, water-retentive chemicals, water stress, farmyard manure, factory filter mud.

INTRODUCTION

The national average yield of field-grown cooking tomato in Mauritius is 12 t ha^{-1} (CSO, 1997), which is only half of the achievable yield (Rughoo et al 1997). One of the main causes of this yield gap is lack of water. The scarcity and high cost of water for irrigation was ranked second in a diagnostic survey of tomato production problems conducted in 1996 (Govinden et al 1997a) and the use of water-retentive chemicals (hydrogels) as a possible solution was given high priority in a tomato research planning workshop held subsequently (Govinden et al 1997b).

Water-retentive chemicals are polymers, which become gels in contact with water. Woodhouse and Johnson (1991) classified polymers into 3 groups: starch-polyacrylonitrile graft polymers (starch co-polymers), vinyl alcohol-acrylic acid co-polymers (polyvinylalcohols) and acrylamide sodium acrylate co-polymers (cross-linked polyacrylamides). Loosely described as super absorbents, these substances can hold up to a thousand times their own weight of water (James and Richards 1986). When mixed with the soil, they form an amorphous gelatinous mass on hydration and are capable of cyclical absorption and desorption over long periods of time, hence acting as a slow-release source of water in the soil. Under rain fed conditions they may be expected to increase the survival of seedlings by increasing the time to wilting between rainfall events. Under certain conditions this may lead to increased yields.

The role of hydro gels in decreasing water stress and increasing hours to first wilting has not been clearly demonstrated. Conclusive results were obtained with marigold and zinnia (Gehring and Lewis

1980), Easter lily and chrysanthemum (Bearce and McCollum 1997), and maize (El-Amir et al 1991). However, they were reported to be ineffective on African marigold grown in sand (James and Richards, 1986). Letey et al (1992) reported that the increase in time to wilting was too little to have any significant effect in container-grown marigolds.

Similarly, the effects of hydrogels on seedling survival have been inconsistent. Increases in seedling survival were reported with maize and soybean (Chaudhry et al 1995), and cucumber (Al-Harbi et al 1999). Swietlik (1989) reported that hydrogels provided no benefit in the establishment of young grapefruit trees under field conditions. Growth of azalea and impatiens was even depressed, probably through toxicity (Flannery and Busscher 1982). In laboratory tests, accelerated deterioration of the gels was noted when they were placed in solutions containing Ca, Mg, Na or Fe salts (Johnson 1984).

In the one study carried out under field conditions in Mauritius a cross-linked acrylamide acrylate co-polymer increased soil moisture holding capacity, but did not increase cane and sugar yields when applied at the rate of 10 kg/ha (Ng Cheong et al 1999).

In tomato, seedling survival, growth and dry weight were unaffected by hydrogel incorporation in the soil (Bearce and McCollum 1997; Bres and Weston 1993; Adams and Lockaby 1987; and Pill and Jacono 1984). Significant increases in total leaf area, shoot fresh and dry weight and relative growth rate (Al-Harbi et al 1999) and advanced flowering in tomato (Ouchi et al 1990), were probably due to an increase in water holding capacity and aeration of soils. Wallace and Wallace (1990) obtained high tomato yields with hydro gels.

It can be concluded that the effects of hydro gels are probably dependent on application rates, on crops species and on soil conditions. Field trials are warranted.

In Mauritius, soil amendments as farmyard manure or factory filter muds (scums) are extensively used in the production of tomato, especially under rain fed conditions (Govinden et al 1997a). Besides providing nutrients to crops, these soil amendments improve the water-holding capacity of soils (Haynes and Naidu 1998). Whether locally they are principally applied for their macro- or micronutrients or their water-holding capacity or soil conditioner effect or a combination of these, is not known.

The objective of this study was to investigate the effects of two hydro gels, with or without farmyard manure or factory filter muds on the survival of tomato seedlings following transplantation and on yield under irrigated and rainfed conditions.

MATERIALS AND METHODS

The study was carried out in Mauritius during the winter and summer seasons of 1997 and 1998. The winter trials were planted in March and April and harvested as from June, while the summer ones were planted in September and October and harvested as from November. The trials were located on experiment stations as well as on farmers' fields in the following localities: Réduit, Union Park, Belle Rive and Pamplemousses (MSIRI experiment stations), FUEL S.E. and Société Sucrière de Rivière du Rempart (on-farm trials).

Cooking tomato var. Sirius was used. Before sowing, seeds were soaked for 25 minutes in water kept at 50 ^{0}C followed by 15 minutes in a 10% solution of sodium triphosphate to eliminate bacteria and viruses.

The experiment consisted of 9 treatments. Two commercially available polyacrylamide hydrogels (Hydro gels A and B) were used. They were applied at the rate of 15 kg ha^{-1} alone or in combination with either farmyard manure or factory filter muds at the rate of 15 and 10 t ha^{-1}, respectively. The three other treatments consisted of manure alone, factory filter muds alone and a control, where neither the hydro gel nor the organic soil amendment was used. The experiment was a 3x3 factorial arranged in split-plot design with 4 replicates: Factor A- the organic soil amendments - were assigned to the main plots, and Factor B- the hydrogels - to the subplots. There were 9 trials in all; 6 under irrigation and 3 under rain fed conditions. Irrigated trials were given water by sprinklers as and when necessary. The

plots consisted of four 5m-long rows spaced 1.0 m apart. Within row spacing was 0.5m. Crop husbandry practices were as recommended by Govinden et al (1995) for the commercial production of cooking tomato.

At planting, the inorganic fertilizer 13:13:20:2 (13%N, 13%P_2O_5, 20%K_2O and 2%MgO) were placed in the holes at the rate of 0.4 t ha^{-1}. The holes were then filled with soil. A small cavity was dug in the middle of the holes and the hydro gels were placed in the cavities so as to allow maximum contact with the roots of the seedlings. Only one seedling was transplanted per hill. The fields were watered profusely after transplantation to allow the hydro gels to absorb water. In the rain fed trials, water was applied only once at transplantation.

Ten days after transplantation the number of seedlings, which had survived, was counted and missing plants were replaced. In this study, seedling survival is defined as the number of seedling, which were alive at 10 days after transplantation. At 17 days, a side dressing of Calcium Ammonium Nitrate (26%N) at the rate of 0.15 t ha^{-1} was applied at the base of the plants and covered lightly with soil. Weeds were removed manually, as and when required. Fruits were harvested weekly at the breaker to ripe stage. Yield was measured on the two centre rows, the outer rows serving as guard rows.

The results of the 9 trials were analysed statistically and the across-location effects of the hydro gels and the organic soil amendments on seedling survival and yield were calculated.

RESULTS AND DISCUSSION

Seedling survival

Under Irrigation

On average, 87% of the transplanted seedlings survived. There were only small differences between the effects of the treatments which were within ±3% of the mean. Since the trials were irrigated after transplantation, the soil around the seedlings was kept moist, and this explains why most of the seedlings survived and the treatments had no significant effects.

Wherever irrigation is available on a regular basis, there is no benefit in using either the hydro gels or the organic soil amendments for enhancing seedling survival. However, it is important to irrigate the field just after transplantation and to continue irrigation for a few days more to keep the soil moist. Ideally, the field should also be irrigated and the seedlings themselves should be watered before transplantation in order to minimize transplantation shock.

Under rainfed conditions

In the absence of the soil amendments, only 11% of the seedlings survived (**Table 1**). This shows that in the absence of irrigation after transplantation, water was inadequate for the seedlings to become established. Significantly more seedlings survived in plots where hydrogel or organic matter was used. Bres and Weston (1993) reported that gel amendment did not affect seedling growth whereas Adams and Lockaby (1987) found that tomato seedlings planted in a media with a super absorbent polymer remained viable for a longer period of time, which increased with increasing polymer application rates. When used alone, the two hydrogels gave similar survival percentages. Likewise, the two organic soil amendments had similar effects though none of them was as effective as the hydro gels in improving seedling survival.

Best results were obtained when a hydro gel was combined with an organic amendment. Since the hydro gels had become hydrated with the first irrigation, they conserved some water for the seedlings. Farmyard manure and factory filter muds must have had a similar effect, although they were not as effective as the hydro gels.

Table 1 Effects of 2 hydro gels and 2 organic soil amendments on seedling survival of tomato under rainfed conditions at 3 sites

Amendment	Percent seedling survival (Mean of 3 sites)		
	Hydrogel A	Hydrogel B	Control (No Hydrogel)
Manure	68 a	63 ab	39 d
Factory filter muds	62 b	60 b	38 d
Control (No organic amendment)	54 c	53 c	11 e

Mean values followed by the same letter do not differ significantly at P<0.05 according to the DMR Test

When the hydrogels were applied alone, only slightly more than 50% of seedlings survived under rain fed conditions while with the organic soil amendments alone only about 40 % of the seedling survived. The superiority of the hydro gel may be due to a difference in their inherent capacity to conserve and release water, but it may also be due to a dosage effect. The application rates of the hydro gels and of the organic amendments were markedly different. Similarly, the synergistic effect of the combinations of hydro gels and organic matter could be due to a dosage effect. Such a synergistic effect has not been shown in the literature previously. Trials with application rates of the soil amendments would be needed in order to establish the nature of the synergistic action.

Only 68% of the seedlings survived in the best treatment. Tomato growers would not be satisfied with such a low seedling survival rate. In practice, they would endeavour to achieve as high a plant stand as possible through a combination of practices such as raising the seedlings in plastic bags, the use of organic soil amendments and irrigation of the seedlings before and after transplantation. These practices each have a cost. The cost per hectare of the hydro gels A and B were MUR 5175 and 4350, respectively, plus MUR 636 for applying them in the field. Given that factory filter muds are readily available at a relatively low cost (approximately MUR 200/tons), it would be more profitable to use it rather than the hydro gels, to plant more than one seedling per hill, to recruit more than once, if necessary, and to endeavour to apply some water at transplantation.

Yield

In this study, after seedling survival had been recorded, plots were recruited, more than once in certain treatments, in order to bring the plant stand as close as possible to the maximum. Yield was measured at this maximum plant stand. This was done to separate the effects of the treatments on plant stand from the effects on yield.

Under Irrigation

As was expected, under irrigation, the hydro gels had no significant effect on yield, which averaged 12.5 t/ha. Significantly higher yields were obtained with manure or factory filter muds, which gave 14% and 10% respectively more than the control. The increases in yield with the organic amendments were not due to higher seedling survival rates nor to the relief of water stress, which is not likely to have occurred under irrigation. It can be attributed to a soil conditioner or micronutrient effect. Organic manures increase soil organic matter content and hence improve increased water holding capacity (Haynes and Naidu, 1998). Farmyard manure is a known source of several micronutrient (Lorenz and Maynard, 1988).

Under rainfed conditions

The locality x treatment interaction was significant (**Table 2**), possibly because of a two-fold difference in mean yield from the lower-yielding site to the higher-yielding one. This difference can be attributed to a difference in rainfall. Across sites, very low yields of 3.2 tha^{-1} were obtained when neither hydro gels nor the organic amendment was used, which confirms that in these trials the crop was severely water-stressed. Under these conditions, the hydro gels had no significant effect on yield. This is probably because the amount of hydro gel used (15 kg ha^{-1}) was so small that only a small proportion

of the roots was in contact with the hydro gel. In contrast, the organic amendments increased yield significantly probably because far more manure or factory filter muds were used. More water could have become available to the crop directly as a result of the water conserved by the organic soil amendments and indirectly through improved root growth (Lorenz and Maynard 1988) leading to an increase in the volume of soil explored. The higher effectiveness of farmyard manure compared to factory filter muds could be a dosage effect, manure having been applied at 15 t ha^{-1} and factory filter muds at 10 t ha^{-1}.

Whenever the crop experiences water stress, the most appropriate solution for tomato growers would be to use organic soil amendments either as farmyard manure or factory filter muds, the large increase in yield more than covering the extra costs.

Table 2 Effects of 2 hydrogels and 2 organic soil amendments on the yield of cooking tomato under rainfed conditions at 3 sites

Treatment	Yield *t ha*$^{-1}$			
	Site 1	Site 2	Site 3	Mean
Manure + Hydrogel A	5.8 b	12.4 a	16.2 a	11.3
Manure + Hydrogel B	3.9 d	12.8 a	15.4 ab	10.7
Manure only	5.3 c	12.4 a	14.3 b	10.7
Factory filter muds + Hydrogel A	6.8 ab	6.0 b	12.0 c	8.3
Factory filter muds + Hydrogel B	7.9 a	6.2 b	11.7 c	8.6
Factory filter muds only	6.4 ab	5.8 b	9.0 d	7.1
Hydrogel A	4.7 c	2.7 c	6.3 e	4.6
Hydrogel B	3.8 d	2.5 c	5.9 e	4.1
Control (No amendment)	3.9 d	2.8 c	2.7 f	3.2
Mean	5.4	7.1	10.4	7.6± 0.8

Mean values followed by the same letter do not differ significantly at P<0.05 according to the DMR Test

CONCLUSION

Under irrigation, the hydrogels had no effect on seedling survival or yield and were therefore of no benefit. Although farmyard manure or factory filter muds had no effect of seedling survival, yet they increased yield by 14 % and 10%, respectively.

Under rainfed conditions, significantly more seedlings survived in plots where the hydro gels or organic amendments were used. However, given the cost of the hydro gel, it is probably better to use the organic amendments alone and to endeavour through whatever means available, to improve plant stand. When plant stands were maximum, significantly higher yields were obtained with manure and factory filter muds, but not with the hydro gels. It is therefore concluded that under rain fed conditions, organic soil amendments either as manure or factory filter muds are worthwhile whereas the hydro gels are not.

ACKNOWLEDGEMENTS

We acknowledge Field Officers in charge of the MSIRI Experiment Stations at Réduit, Pamplemousses, Union Park and Belle Rive and Managers, Agronomists and Heads of Sections of collaborating sugar estates for land and help in the management of the trials. Thanks are presented to Mr B. Clement of Spec Mart for supplying one of the hydro gels under experimentation and the Director and the Deputy Director (Biology) for reviewing the manuscript.

REFERENCES

ADAMS JC and LOCKABY BG. 1987. Commercially produced super absorbent material increases water-holding capacity of soil medium. *Tree-Planters'-Notes* 38:1, 24-25 (Abstract)

AL-HARBI AR, AL-OMRAN AM, SHALABY AA and CHOUDHARY MI. 1999. Efficacy of a hydrophilic polymer declines with time in greenhouse experiments. *Hort Sc*i. 34: 2, 223-224 (Abstract)

BEARCE BC and MC COLLUM RW. 1997. A comparison of peat-like and noncomposted hardwood-bark mixes for use in pot and bedding-plant production and the effects of a new hydrogel soil amendment on their performance. *Flor. Rev*. 161 (4169): 21-23, 66 (Abstract)

BES W and WESTON LA. 1993. Influence of gel additives on nitrate, ammonium, and water retention and tomato growth in a soilless medium. *Hort Sci*. 28: 10, 1005-1007 (Abstract)

CHAUDHRY MA, TAHIRA-AHMAD KHAN MFA and AHMAD T. 1995. Effect of polymers on germination, plant height and permanent wilting point of miaze (*Zea mays* L.) and soybean (*Glycine max*). *Pak. Jour. Scien. Ind. Res*. 38: 8, 308-311 (Abstract).

CSO *see under* Central Statistical Office

CENTRAL STATISTICAL OFFICE. 1997. *Digest of Agricultural Statis*tics, 1995. Central Statistics Office, Ministry of Economic Development and Regional Cooperation.

EL-AMIR S, HELALIA AM, WAHDAN A and SHAWKY ME. 1991. Effect of two polymers on corn (Zea mays L.) growth and water economy in sandy soils. *Soil Tech*. **4**: 2, 177-181 (Abstract).

FLANNERY RL and BUSSCHER WJ. 1982. Use of a synthetic polymer in potting soils to improve water holding capacity. *Comm. Soil Sci. Plant Anal*. 13:103-11

GEHRING JM and LEWIS AJ. 1980. Effect of hydrogel on wilting and moisture stress of bedding plants. *J. Amer. Soc. Hort. Sci*. 105, 511-513.

GOVINDEN N, RAMASAMY S, EVARISTE C, RAMNAUTH C and GUMANI A. 1997a. *Problems of small-scale tomato growers: report of a diagnostic survey carried out jointly by MSIRI, AREU and FSC*. Occ. Rep No 12: 18 pp. Reduit, Mauritius Sugar Industry Research Institute.

GOVINDEN N, RAMASAMY S, EVARISTE C and GUMANI A. 1997b. *Tomato research and extension needs: report of a diagnostic survey carried out jointly by MSIRI, AREU and FS*C. Occ. Rep No 14: 51 pp. Reduit, Mauritius Sugar Industry Research Institute.

GOVINDEN N, RUGHOO M, MCINTYRE G, SAUMTALLY S and RAJABALEE A. 1995. *Growing Tomato*. Adv. Bull. No 7, 11p. Reduit, Mauritius Sugar Industry Research Institute

HAYNES RJ and NAIDU R. 1998. Influence of lime, fertilizers and manure applications on soil organic matter content and soil physical conditions: A review. *Nutrient Cycling in Agroecosystems* 51:2, 123-137 (Abstract).

JAMES EA and RICHARDS D. 1986. The influence of iron source on the water-holding properties of potting media amended with water-absorbing polymers. *Scientia Hort.* 28 : 201-208.

JOHNSON MS. 1984. Effect of soluble salts on water absorption by gel-forming soil conditioners. *J. Sci. Food Agric.* 35:1063-1066

LETEY J, CLARK PK and AMRHEIN C. 1992. Water-sorbing polymers do not conserve water. *Calif. Agric*. 46: 3, 9-10.

LORENZ OA and MAYNARD DN. 1988. Handbook for vegetable growers. 3rd Edition. Wiley and Sons

NG CHEONG LR, AH-KOON D, MUTHY K and SOOPRAMANIEN C. 1999. Gel forming co-polymers applied at manufacturer's recommended rate increase soil moisture without affecting sugarcane yield. [Submitted for publication in *Sugar Cane*].

OUCHI S, NISHIKAWA A and KAMADA E. 1990. Soil-improving effects of a super-water-absorbent polymer (part 2). Evaporation, leaching of salts and growth of vegetables. *Jap. Jour. Soil Sci. Plant Nutrition* 61:6, 606-613 (Abstract)

PILL WG and JACONO CC. 1984. Effects of hydrogel incorporation in peat-like an tomato growth and water relations. *Comun. Soil Sci. Plant Anal*. 15(7), 799-810

RUGHOO M, GOVINDEN N and GOWREA B. 1997. Yield and characteristics of cooking tomato var. Sirius. *Revue Agric. Sucr. Ile Maurice* 76 (2): 38-43

SWIETLIK D. 1989. Effect of soil amendment with viterra hydrogel on establishment of newly-planted grapefruit trees cv Ruby Red. *Commun. Soil Sci. Plant Anal*. 20 (15&16), 1697-1705).

WALLACE A and WALLACE GA. 1990. Interactions encountered when supplying nitrogen and phosphorus fertilizer and a water-soluble polyacrylamide to soil. Jour. *Plant Nutrition* 13:3-4, 343-347 (Abstract).

WOODHOUSE JM and JOHNSON MS. 1991. Effects of soluble salts and fertilizers on water storage by gelforming soil conditioners. *Acta Hort*. 294 ,261-269

IRRIGATING SUGAR CANE AT VARYING DOSES AND FREQUENCIES: EFFECTS ON SOIL MOISTURE AND YIELD

LR Ng Cheong, D Ah-Koon* and *K Muthy

Mauritius Sugar Industry Research Institute

ABSTRACT

Overhead irrigation is the most important system in Mauritius, representing more than 80% of irrigated land for miller-planters in 1997. The effects of irrigation dose and frequency on cane and sugar yields using a solid-set sprinkler system were assessed at Tamarin section, Médine S.E. over seven harvest seasons. Higher irrigation doses led to significantly higher cane and sugar yields. Cane yield increments per unit of water applied (compared to rain fed treatment) amounted to 0.090, 0.094, 0.083 and 0.082 t ha^{-1} mm^{-1} for 0.25, 0.5, 0.75 and 1.0 ETc treatments respectively, equivalent to a productivity of 0.112, 0.117, 0.104 and 0.102 t ha^{-1} mm^{-1} of water evapotranspired for an irrigation efficiency of 80%. Productivity of irrigation was thus higher than the average productivity of 0.097 t ha^{-1} mm^{-1} of water evapotranspired derived for a group of sugar-producing countries and the 0.5 ETc treatment had a productivity close to the maximum value of 0.123 t ha^{-1} mm^{-1}.

Furthermore, there was no difference in cane or sugar yields between weekly and fortnightly irrigation, even though more water was consistently applied with weekly irrigation. The most efficient use of irrigation water in the relatively deep soils of Tamarin would thus be attained with 0.5 ETc irrigation at fortnightly interval.

Keywords : sugarcane, overhead irrigation, irrigation frequency, irrigation dose, soil moisture, yields, Mauritius

INTRODUCTION

Overhead irrigation is the main method of water application to sugar cane in Mauritius. In 1991, this system represented 68% of the total 12 800 ha irrigated area for miller-planters and increased to 82% of a total 13 300 ha by 1997 (Anon. 1991, 1997). This increase is mainly due to the introduction of more reliable systems with lower energy requirements than the older "big gun" systems, such as centre pivot and dragline. The trend island wide is for the replacement of surface and "big gun" systems by centre pivot and dragline, with little development in the field of drip irrigation.

While drip irrigation has been extensively studied and reported upon (Batchelor and Soopramanien 1993), the overhead system has received much less attention, being less difficult to manage than drip. The normal management practice with the "big guns" has been to apply a fixed dose over a fixed interval, and to modify the interval depending on rainfall and water availablity. For instance, one inch of water, i.e. 25 mm, could be applied on a fortnightly basis and if there is a water shortage, this interval could be lengthened to one month or longer, with the cane being much more water-stressed at the end of the cycle.

For rational irrigation management, it is more appropriate to use crop water requirements and effective rainfall to determine irrigation water demand. It is then possible to apply water treatments to fully or partially satisfy crop water demand while varying the irrigation interval. This could lead to the determination of an optimum dose and interval for overhead irrigation.

A study was therefore initiated to compare the impact of differing irrigation dose and frequency on soil moisture content and cane and sugar yields.

MATERIALS AND METHODS

The trial was conducted at Tamarin section of Médine Sugar Estate, in the sub-humid western region of the island. A randomised block design was applied, with four blocks, four irrigation doses (0.25, 0.5, 0.75 and 1.0 ETc) and two irrigation frequencies (weekly and fortnightly), plus a rain fed treatment. Each plot consisted of six cane rows of 10 m length, planted with variety *R570*, with interrows spaced at 1.62 m.

The soil is a Low Humic Latosol of the Richelieu family equivalent to a tropeptic haplustox in the USDA classification (Parish and Feillafé 1965). It is relatively deep and stone free and has total and readily available water contents of 75 and 45 mm respectively, for a rooting depth of 60 cm.

Meteorological data were taken on a daily basis from a station at the experimental site. Atmospheric demand was calculated using the modified Penman formula (Doorenbos and Pruitt 1984). Crop water demand (ETc) was calculated on a weekly basis from the Penman ETo data and the crop factor (Doorenbos and Pruitt 1984). Irrigation doses were adjusted to account for effective rainfall. Irrigation was applied through a solid-set system of sprinklers giving controlled volumes of water.

Soil moisture content was monitored with an IH Type II neutron moisture probe (Bell 1976). The readings were taken on a weekly basis, with the probe being inserted into aluminium access tubes placed in the rows and interrows of each treatment. Readings were obtained in count rates that were converted to moisture volume fraction (MVF) using a calibration curve (Hodnett et al. 1991), and then averaged to give a representative value of the soil moisture content. MVF data were then normalized over a depth of 60 cm using the procedure described by Batchelor (1992) to remove the effects associated with soil heterogeneity.

Cane was harvested 16 months after planting (for plant cane) and every 12 months for the six subsequent ratoons. Strips 10 m long were harvested in the experimental cane rows within each block, weighed and averaged to give the cane yield results expressed in t ha^{-1}. Samples were analysed to obtain the average Industrially Recoverable Sucrose Content (IRSC). By combining cane yield and IRSC figures, sugar yield in t ha^{-1} was obtained for each treatment.

RESULTS AND DISCUSSION

Seasonal rainfall and irrigation applied

The total rainfall for each of the seven seasons was much lower than the long-term mean for the years 1951 - 1980 (Padya, 1984). In the 3rd ratoon season, which was the wettest of the seven seasons, total rainfall was lower than long-term mean by 200 mm (**Figure 1**). On average, rainfall for the crop cycle was lower than long-term mean by 350 mm.

Seasonal effective rainfall was low, about 370 mm on average for the crop cycle (**Table 1**). As a result, irrigation water demands were high but the calculated doses could not be applied at certain times owing to water shortage or practical problems.

For all four irrigation doses, the seasonal water application was higher for the weekly treatments as compared to the fortnightly ones. With the fortnightly treatments, the soil had more time to dry out owing to the longer interval between each water application and rainfall was therefore more effective.

Soil moisture content

The evolution of soil moisture content throughout the season was fairly similar for all seven seasons. Changes in normalized soil moisture contents for a rooting depth of 60 cm are illustrated for the 4th ratoon crop. The treatments were averaged in terms of dose (**Figure 2**) and frequency (**Figure 3**). In the interval immediately after harvest, crop water demand was low and the soil moisture level did not change significantly for the first months. Thereafter, the application of larger irrigation amounts and the onset of the rainy season led to important changes in soil moisture. For the last five months of the

season, rainfall contribution to soil moisture became less significant and the effects of irrigation doses became more marked.

Figure 1 Seasonal rainfall and long-term mean

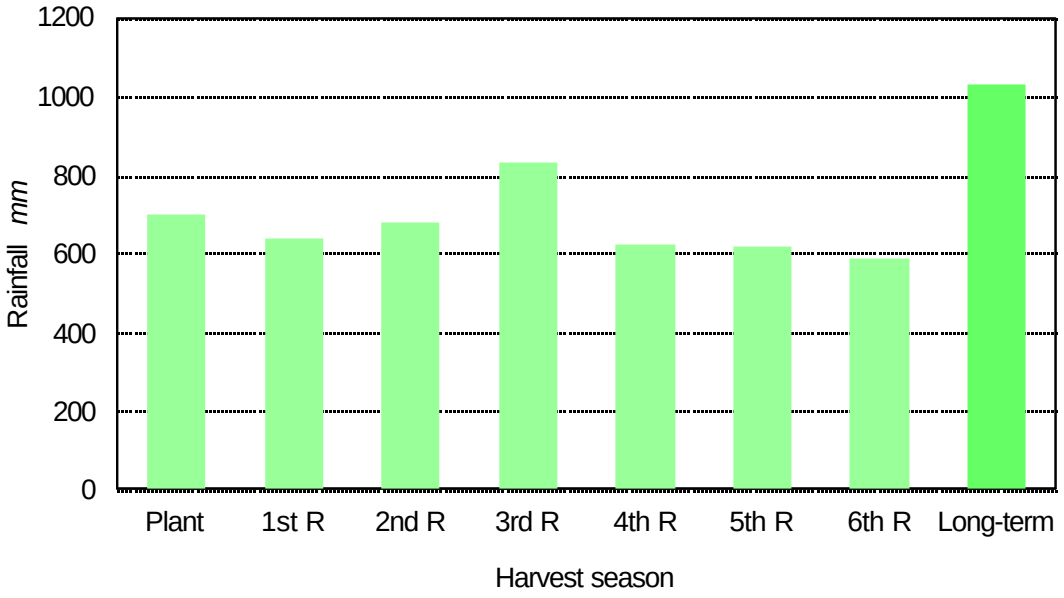
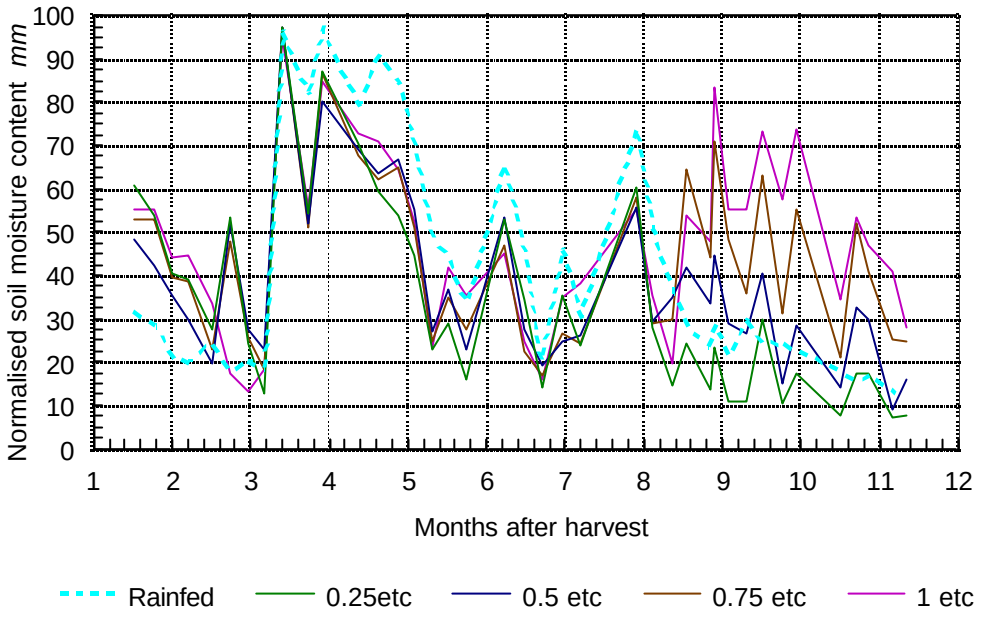


Table 1 Seasonal effective rainfall and irrigation applied

ER *mm*		Seasonal irrigation applied *mm*							
		Every week				Every fortnight			
		0.25	0.5	0.75	1.0	0.25	0.5	0.75	1.0
		ETc	ETc	ETc	ETc	ETc	ETc	Etc	ETc
Plant cane	345	534	706	883	1074	530	696	871	1057
1st Ratoon	353	267	358	449	539	260	344	426	508
2nd Ratoon	402	291	432	585	746	268	393	540	692
3rd Ratoon	429	316	473	642	828	291	417	597	773
4th Ratoon	386	317	452	589	726	312	438	563	689
5th Ratoon	315	255	354	452	540	253	348	442	536
6th Ratoon	350	288	503	732	962	248	457	649	851
Average	368	324	468	619	774	309	442	584	724

Figure 2 Evolution of soil moisture content



With respect to irrigation dose, higher water application led to higher soil moisture contents. Thus, the 1.0 ETc treatments were consistently the wettest and 0.25 ETc the driest. However, this trend disappeared during the rainy season (3 to 5 months after harvest) when less irrigation was applied and rainfall evened out the differences. Soil moisture in the rain fed treatment decreased more slowly than in the irrigated ones during the rainy season, since water abstraction was lowest in this treatment owing to the younger development stage of the cane.

As far as irrigation frequency is concerned, there were little differences for the rainy season. However, when soil moisture was increasing, fortnightly treatments tended to reach higher peaks. The reverse is also true, i.e. fortnightly treatments had lower moisture on the drying curve. Changes in soil moisture for fortnightly treatments thus displayed higher amplitudes. With increasing irrigation interval, it can be assumed that the amplitude of moisture changes would be even higher and minimum soil moisture content lower. The average minimum moisture content of the fortnightly treatments was lower than the weekly ones by at least 10 mm. An irrigation interval of 3 weeks or more would mean that minimum soil moisture would be lowered by a further 10 mm and the cane would then be significantly stressed.

Yields

The average cane and sugar yields for the seven cropping seasons are given in **Table 2.**

In line with the seasonal soil moisture contents, significantly higher yields were obtained with higher irrigation doses. Cane yield increment per unit of water applied (compared to rain fed treatment) amounted to 0.090, 0.094, 0.083 and 0.082 t ha^{-1} mm^{-1} for 0.25, 0.5, 0.75 and 1.0 ETc treatments respectively. With irrigation efficiency estimated at 80%, the cane yield increment per unit of water evapotranspired is estimated at 0.112, 0.117, 0.104 and 0.102 t ha^{-1} mm^{-1} for the four treatments. Productivity per unit of water evapotranspired was thus higher than the average value of 0.097 t ha^{-1} mm^{-1} derived for a group of sugar-producing countries over an evapotranspiration range of 600 to 3800 mm, but lower than the maximum value of 0.123 t ha^{-1} mm^{-1} (Thomson, 1976). The 0.5 ETc treatment gave the best return on water application, producing a yield increment that was only slightly lower than the maximum value.

Figure 3 Evolution of soil moisture (Frequency)

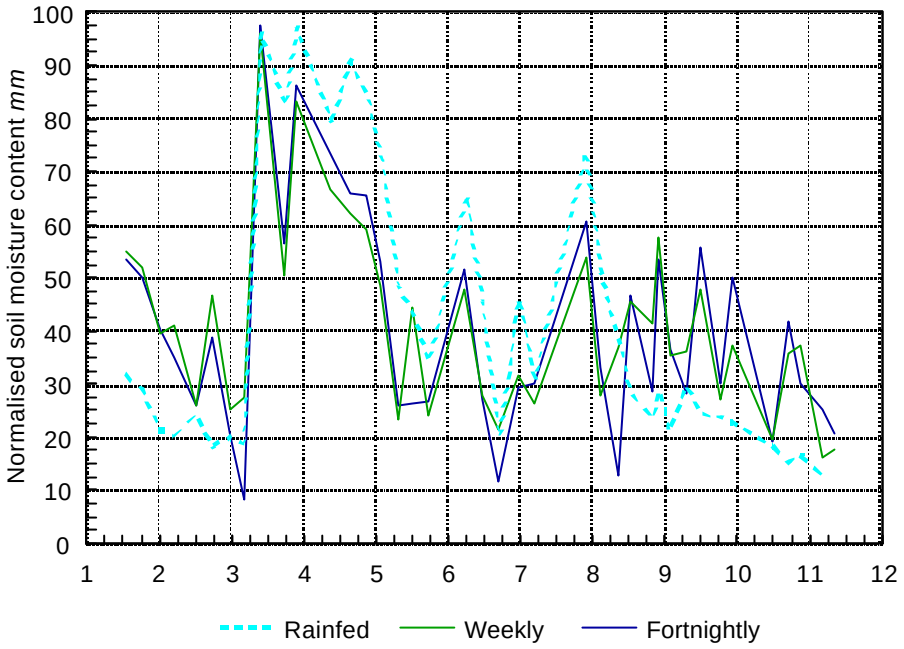


Table 2 Average cane and sugar yields and IRSC for seven seasons

Yield *t ha*$^{-1}$		
	Cane	Sugar
Effect of dose		
0.00 ETc	49.2	6.3
0.25 ETc	77.7	9.5
0.50 ETc	91.9	10.9
0.75 ETc	98.8	11.7
1.00 ETc	110.4	12.9
LSD (P = 0.05)	6.4	0.7
Effect of frequency		
Weekly	86.1	10.3
Fortnightly	85.1	10.2

Furthermore, there was no significant difference in cane and sugar yields between weekly and fortnightly treatments even though more water was applied to the first group of treatments, leading to higher soil moisture contents. There was thus no yield advantage to be gained with the lower irrigation interval even though it used up more water. This lack of difference indicates that the additional water stress imposed by the longer irrigation interval was not detrimental to yield. However, from the soil moisture evolution, it can be assumed that further increases in interval will inevitably lead to stress and eventually yield depression.

CONCLUSION

For the region of Tamarin, with a relatively deep soil, there was no advantage in reducing the irrigation interval from fortnightly to weekly. On the contrary, when overhead irrigation was applied on a fortnightly interval rather than a weekly one, seasonal water requirement was lower, with no significant decrease in cane or sugar yield, whatever the irrigation dose. However, since the amplitude in soil moisture changes is higher with the fortnightly treatment, it is probable that further increasing the irrigation interval would eventually be detrimental to the crop since longer stress periods would be induced. With higher irrigation doses, higher soil moisture contents and yields were obtained. For highest yields, the full crop water requirement has to be met and the highest-yielding irrigation treatment was therefore 1.0 ETc irrigation at fortnightly interval. However, the highest yield increment per unit of water applied would be obtained with 0.5 ETc irrigation at fortnightly interval.

ACKNOWLEDGEMENT

We wish to thank the Manager of Medine S.E. and the field staff of Tamarin section for their support in conducting this work. Grateful thanks are also due to Director and Deputy Director (Agronomy), MSIRI for their support.

REFERENCES

ANON. 1991. Irrigation survey, miller-planters' land. *Ann. Rep. Maurit. Sug. Ind .Res. Inst*. 37: 21

ANON. 1995. *Ann. Rep. Maurit. Sug. Ind. Res. Inst*. 41: 42

ANON. 1997. Irrigation survey, miller-planters' land. *Ann. Rep. Maurit. Sug. Ind. Res. Inst*. 43: 23

BATCHELOR CH. 1992. Water use and growth of drip-irrigated sugar cane. PhD Thesis, University of Reading.

BATCHELOR CH and SOOPRAMANIEN GC. eds. 1993. *Drip irrigation research*, MSIRI / IH.

BELL JP. 1976. *Neutron probe practice*. Institute of Hydrology Report No 19. Inst.Hydrol, Wallingford, UK.

DOORENBOS J and PRUITT WO. 1984. *Crop water requirements*. FAO Irrigation and Drainage Paper 24. FAO, Rome.

HODNETT MG, BELL JP, AH-KOON D. and SOOPRAMANIEN GC. 1991. *Improved Irrigation Efficiency using Soil Physical Techniques. The case of drip-irrigated sugar cane in Mauritius.* MSIRI / IH.

PADYA. 1984. *The climate of Mauritius.* Meteorological office, Mauritius. 2nd Edition.

PARISH DH and FEILLAFÉ SM. 1965. *Notes on the 1 : 100 000 Soil Map of Mauritius.* MSIRI Occ. Paper No 22.

THOMSON GD. 1976. Water use by sugar cane. *South African Sugar J. 60*: 627 - 635.

MOVEMENT OF ATRAZINE BY RUN OFF FROM SUGAR CANE LANDS IN THE SUPERHUMID REGION OF MAURITIUS

A Mooniaruck, G Umrit **and** *KF Ng Kee Kwong*

Mauritius Sugar Industry Research Institute

ABSTRACT

The movement of atrazine by surface and subsurface (<90 cm) run-offs was studied on 500 m^2 plots at Valetta where the mean rainfall exceeds 3500 mm and sugar cane is planted on land with 5 to 12 degree slopes. On 1 December 1997, atrazine was applied at 2.7 kg a.i. per hectare to ratoon cane with trash lined in alternate interrows, and at 4.0 kg a.i. per hectare to a similar plot left bare. Surface and subsurface run-offs resulting from five high rainfall events occurring until harvest in August 1998 were collected in metal lined troughs installed at the end of each plot. Quantification of atrazine in the run-offs was done by Gas Chromatography Mass Spectrophotometer (GC-MS) and High Performance Liquid Chromatography (HPLC). The present study showed that only 0.02% of atrazine applied to the bare plot was lost by surface runoff as compared to 0.05% in the plot cultivated with sugar cane. Higher concentration of atrazine was observed in subsurface water than in the surface runoff. This indicates that quantification of atrazine in surface runoff alone underestimated the amount of atrazine moved and that the studies carried out in small plots may not provide an accurate reflection of the actual movement of atrazine from sugar cane fields.

Keywords: sugar cane, atrazine, run-off, land use, suspended sediment, Gas Chromatography Mass Spectrophotometer, GC-MS, High Performance Liquid Chromatography, HPLC.

INTRODUCTION

The essential problem in agricultural production has always been one of efficiency i.e. how to produce more from less resources. The development of pesticides has been one solution to this problem. Unfortunately though the use of pesticide in current agricultural production has indeed significantly improved crop yield, it has also adversely affected environmental quality. In this context, numerous studies conducted in USA and Europe have underlined the off-site transport of herbicides by runoff (Ma and Spalding 1997; Pantone et al. 1996). Atrazine (2-chloro-4-ethylamino-6-isopropylamino-s-triazine), a pre-emergence herbicide and moderately persistent in soils is one of the most prevalent herbicide residue detected in surface and ground water (Kreger 1995). According to Ng Kee Kwong *et al*. (1997), approximately 130 tonnes a.i. of this herbicide is applied annually to sugar cane fields, which in public opinion still represents the greatest uncontrolled threat to surface and ground water in Mauritius. Public concern about sugar cane cultivation contaminating water resources in Mauritius is a rational one since atrazine is one of the herbicides frequently detected in ground and surface waters in Mauritius (Ng Kee Kwong et al. 1999). Furthermore sugar cane is planted on high slopes where the mean annual rainfall exceeds 3000 mm (with 70% of the rainfall occurring as high intensity downpours between January and April). The potential for off-site transport of herbicides by surface and subsurface run-off is therefore high.

One basic thrust of agronomic research is to define the best management practice for herbicide application in sugar cane production systems that will maintain a high level of chemical efficacy without accentuating non-point source pollution of non-target areas. The development of best management practice however requires knowledge of the extent to which the herbicides reach rivers and streams by run-off. As this knowledge is lacking not only in Mauritius but also in the entire humid tropics, a study was initiated to determine the movement of atrazine by run-off from sugar cane lands in a superhumid region of Mauritius.

MATERIALS AND METHODS

This study is part and parcel of a large-scale project, started in 1997, and aiming at monitoring the fate of agrochemicals in tropical sugar production. The research site is located at Valetta, a superhumid region receiving more than 3000 mm of rainfall annually. The soil is a Humic Ferruginous Latosol, with a silty clay loam texture (Humic Acrisol according to the FAO/UNESCO classification). The organic C content is 30 g kg^{-1}.

Experimental design

Atrazine was applied at 4.0 kg a.i /ha and at 2.7 kg a.i/ha to the bareland plot and to the ratoon cane plot with trash in alternate interrows, on the 1st December 1997. Metal troughs, 17 m in length were installed at the foot of slopes in each plot to intercept all water and soil moving at the soil surface. Water movement was measured by tipping buckets placed at the downstream end of the trough. The tipping buckets were calibrated to known volumes (16 L). The run-off data could then be related to the time of the day from logger time and amount of rainfall from pluviometer data. Water was sampled from the tipping buckets using 1 cm wide splitters, (split ratio 1:160), and pumped into 2.5 L dark glass bottles kept refrigerated at 4°C. The other three sides of each plot had interceptor drains and soil mounds that diverted unwanted surface flows away from the experimental plots to avoid contamination. Shallow sub surface water (<90 cm) was intercepted by plastic lined, 90 cm deep gravel filled trenches, located underneath the metal troughs. It was expected that all water moving through the root zone would be collected at the lower end of the plots and diverted into a small tipping bucket connected to a logger.

Atrazine analyses in water

Prior to analysis, the pH of the water samples was determined for monitoring purposes. Low sediment waters were extracted with dichloromethane and hexane in three steps. The solvent extracts were combined and evaporated under vacuum, after which they were reconstituted in acetonitrile/water or hexane for quantitation by HPLC or GC-MS.

High sediment water samples were filtered and the sediment portions were extracted by refluxing with a mixture of dichloromethane and acetone. The extracts were evaporated, taken into double distilled water before partitioning with dichloromethane and hexane. After evaporation of the organic phase, the herbicide residues as well as the filtered water samples were analysed in the same way as for low sediment water samples.

Soil sampling and atrazine quantification

Following herbicide application to the experimental plot sites at Valetta, soil samples were collected 1, 3, 7, 10 and 15 days after application. Thereafter, less frequent sampling (1-month interval) was carried out. Soil depths sampled were 0-2.5, 2.5-5, 5-10, 10-20 cm during the first ten days after application, and thereafter additional layers (20-30, 30-45 cm) were sampled. The samples were frozen until analysis. Twenty grams of soil sample were extracted with methanol/water (80% v/v methanol) by shaking for 1 hour before partitioning with a mixture of dichloromethane/hexane (50% v/v). After evaporation under vacuum, the residue was reconstituted in acetonitrile/water (1:4 v/v) or in hexane. Quantitation of atrazine was done by both HPLC and GC-MS.

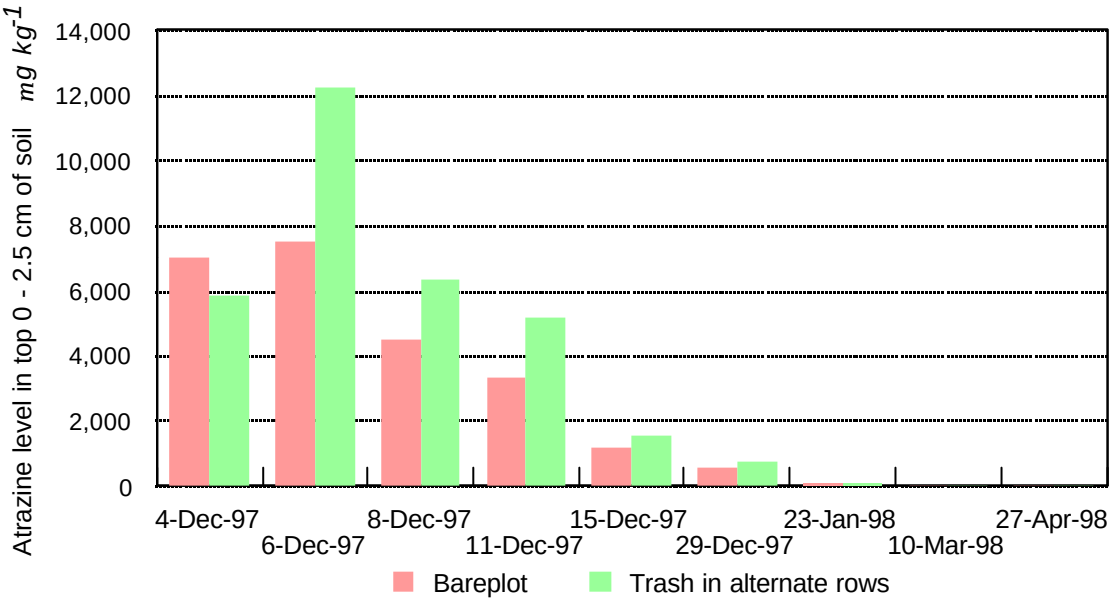
RESULTS AND DISCUSSION

Amount of atrazine carried in surface run-off

From the date of atrazine application to harvest of the sugar cane in August 1998, five run-off events were recorded, the first occurring on 9 January 1998, namely six weeks after applying the atrazine. During that interval, dissipation of atrazine occurred rapidly in the top 2.5 cm soil surface with the

result that when the first run off event occurred, atrazine concentration had declined to less than 7 mg kg^{-1} soil irrespective of the presence or absence of sugar cane plant cover (**Figure 1**). As indicated by Fawcett et al. (1994), the location of a chemical in the soil affects its concentration in run off. At the soil surface rainfall mixes with soil only in a thin mixing zone of approximately 6 to 20 mm and then either infiltrates or runs off. Once a chemical is located below the thin mixing zone, it is no longer susceptible to run off loss.

Figure 1 Dissipation of atrazine in the top 0-2.5 cm of the bare land plot and ratoon cane plot with trash in alternate interrows



Based on the above consideration, the low concentration of atrazine in the top 2.5 cm soil layer when high rainfall causing run-off to occur on 9 January 1998, explained why only little of the atrazine was carried during that first run off-event. As indicated by Weber (1991), the first run-off event generally should have had a disproportionately large impact on the amount of atrazine moved. Instead the first run-off event in our study transported only 0.37 % of the atrazine applied to sugar cane plant cover with trash in alternate interrows.

The amount of a herbicide transported in run-off is also influenced by the intensity and duration of the rainfall event. In this context the most intense rainfall event occurred on 25 February 1998 during which the intensity ranged from 120-180 mm hr^{-1} for 20 minutes. This most intense rainfall event also failed to mobilise significant amounts of atrazine by run-off because, as explained above, the level of atrazine in the top 2.5-cm layer had declined to very low values. Thus only 700 mg ha^{-1} atrazine was moved from the bareland plot (1077 mg ha^{-1} in the presence of sugarcane cover) during that most intense rainfall. Since both the first run-off and that arising from the most intense rainfall did not move appreciable amounts of atrazine, it was therefore not surprising, that over the 1997 to 1998 sugar cane growing season, only 0.02% of the atrazine applied was lost from the bare plot and 0.05% in the treatment with a sugar cane cover and with trash lined in alternate interrows.

Atrazine concentration in run-off

The atrazine concentrations (in both dissolved and sorbed phases) in surface run-off were low and did not exceed the United States Environment Protection Agency drinking water guideline of 3 µg L^{-1} (**Figures 2and 3**).

Atrazine in the dissolved phase occurred at a higher frequency in subsurface than in surface flow for all rainfall events (83% of the samples). The maximum levels of atrazine recorded in the dissolved phase were 0.633 µg L^{-1} in surface flow and 9.167 µg L^{-1} in subsurface runoff. In an undulating landscape such as at Valetta, natural subsurface flow with high atrazine concentration may appear as run-off at points of lower elevation. Furthermore, this high concentration of atrazine observed in solution is expected to diminish with increasing distance from the source. Indeed as reviewed by Mackay et al. (1985), dispersion and spreading during transport result in the dilution of contaminant pulses and the attenuation of concentration peaks.

Atrazine occurred more frequently in the sediment phase in surface runoff than in subsurface for all events inclusive (70% of the samples). The relative amounts of atrazine in the sediment and dissolved fractions however varied from one run-off event to another, and was affected by the concentration of suspended sediment. In the bare plot, 75% of the atrazine was moved bound to sediment in the surface run-off. In contrast the amount of atrazine in the dissolved and sediment phases were similar in the treatment with sugar cane cover.

Figure 2 Atrazine concentrations in surface and subsurface runoffs during the 1997-98 sugarcane crop season at Valetta (Bareland)

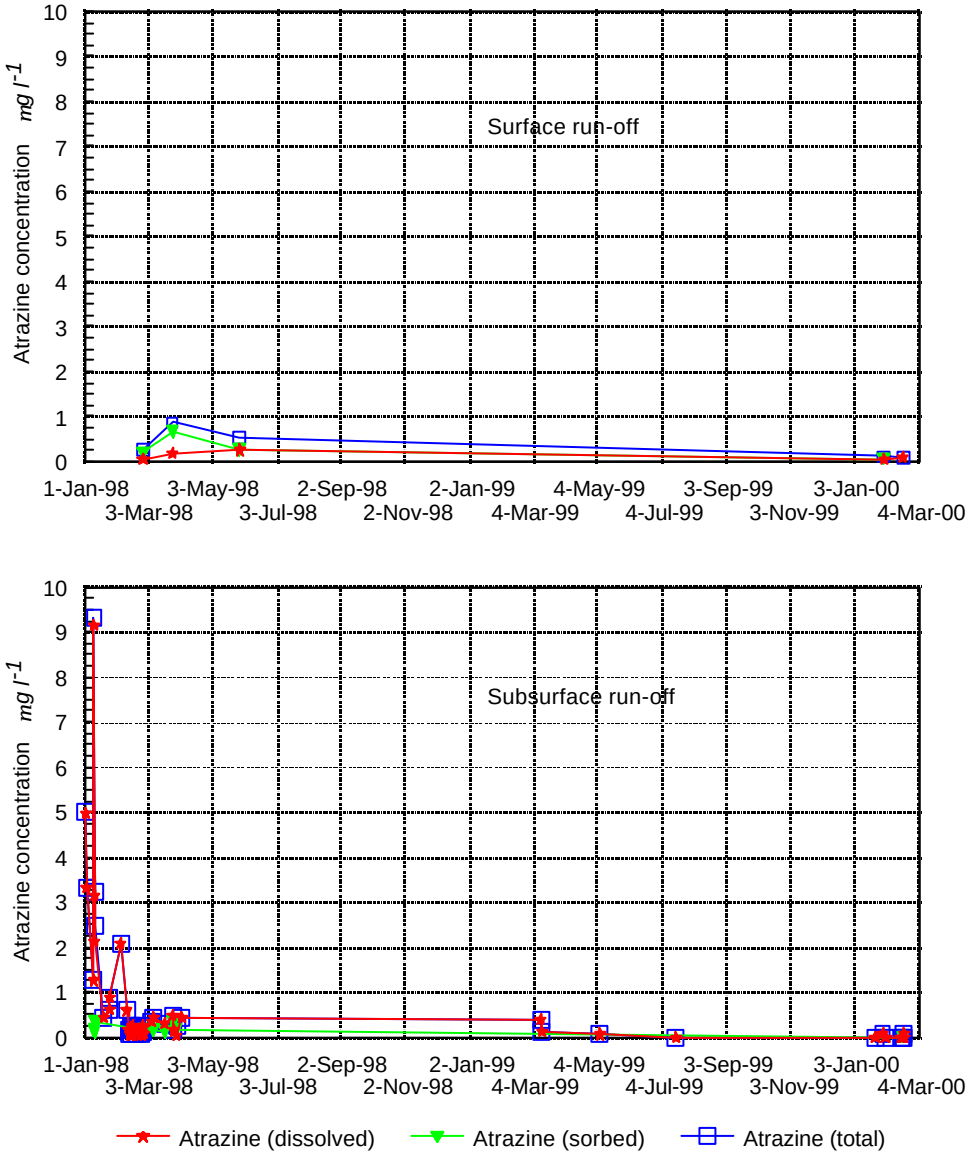
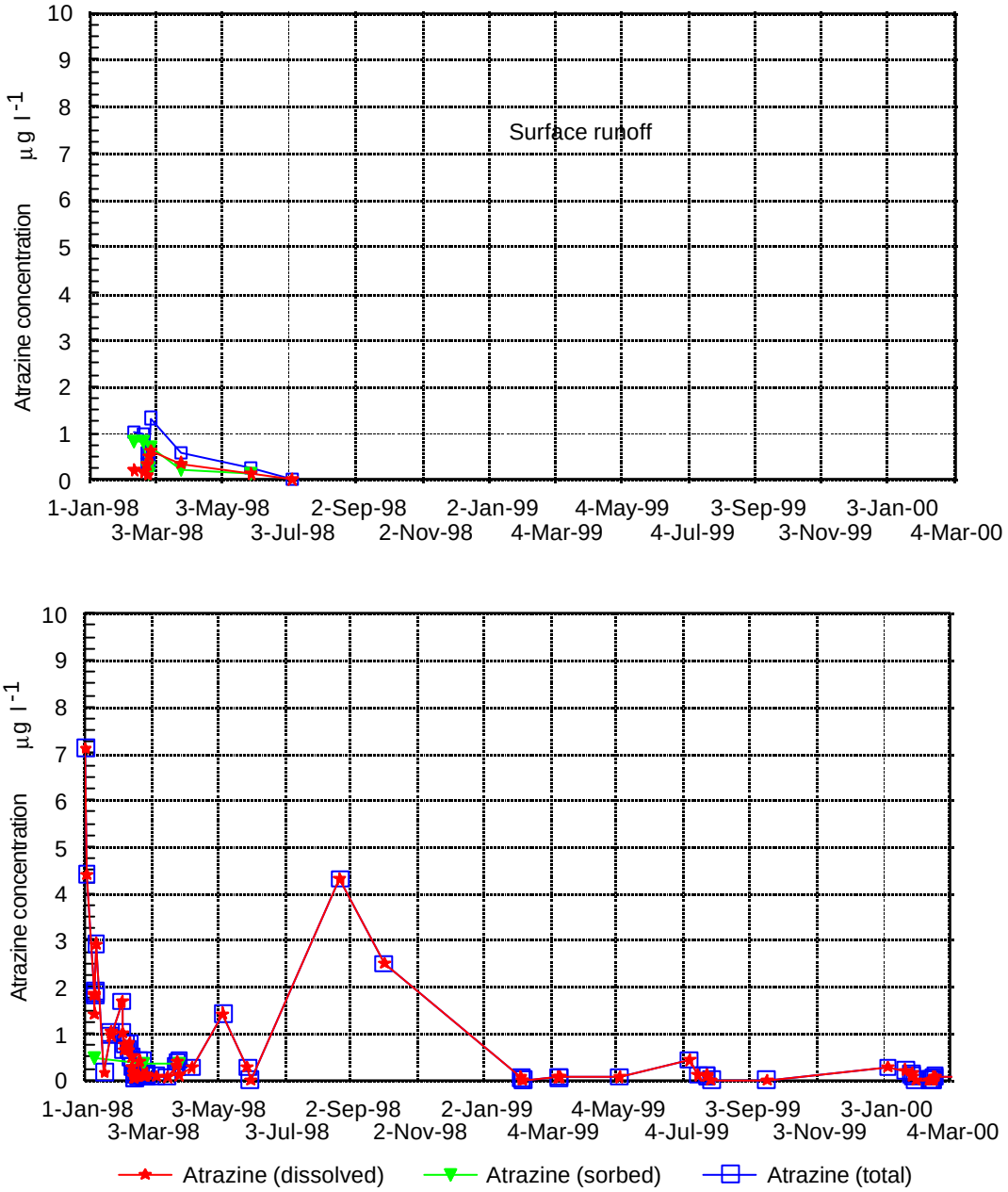


Figure 3 Atrazine concentrations in surface and subsurface runoffs during the1997-98 sugarcane crop season at Valetta(Ratoon cane with trash in alternate rows)



CONCLUSION

The present study indicates that movement of atrazine by surface run-off may not be as extensive as would be perceived or anticipated. Thus less than 0.10% of the atrazine applied was transported in surface run-off irrespective of whether the soil was bare or cropped with sugar cane. This study moreover indicates that measurements of herbicide leakage carried out in small plots e.g. 500 m^2, may not provide an accurate reflection of the concentration of herbicide residues actually found in rivers and streams of large catchments.

ACKNOWLEDGEMENTS

The authors thank the Australian Centre for International Agricultural Research for its financial support (ACIAR Project 9446). The collaboration of the Queensland Department of Natural Resources, Australia, is also gratefully acknowledged. Thanks are also due to the Director and all project team members at the Mauritius Sugar Industry Research Institute for their support and valuable help.

REFERENCES

FAWCETT RS, CHRISTERSEN BR and TIERNEY DP. 1994. The impact of conservation tillage on pesticide run-off into surface water: a review and analysis. *Journal of Soil Water Conservation* 49: 126-135.

KREGER J. 1995. *Pesticide movement to water*. Monograph No 62. p81-86.

MA L and SPALDING RF. 1997. Herbicide persistence and mobility in recharge lake watershed in York, Nebraska. *Journal of Environmental Quality*. 26: 115-125.

MACKAY DM, ROBERTS PV and CHERRY JA. 1985. Transport of organic contaminants in ground water. *Environmental Science and Technology* 19:384-392.

NG KEE KWONG KF, UMRIT G, NOWBUTSINGH M and GOPAUL AK. 1999. Ground and surface water contamination by herbicide residues used in sugar cane fields in Mauritius. *Sugar Cane*. 3: 14-18.

NG KEE KWONG KF, UMRIT G and NOWBOTSINGH M. 1997. Fertilizer and herbicide usage in sugar cane
cultivation in Mauritius. *Revue Agricole et Sucrière de l'ile Maurice*. 3:41-47.

PANTONE DJ, POTTER KN, TORBERT HA and MORRISON JE JR. 1996. Atrazine loss in run-off from no-tillage and chisel-tillage systems on a houston black clay soil. *Journal of Environmental Quality*. 25: 572-577.

WEBER JB. 1991. Fate and behaviour of herbicides in soils. *Applied Plant Sciences*. 5(1): p 28-41.

GERMINATION RESPONSE OF SUGARCANE SETTS OF DIFFERENT VARIETIES AND PHYSIOLOGICAL AGES AFTER HOT WATER TREATMENT

G Permalloo, Y Moutia **and** *S Saumtally*

Mauritius Sugar Industry Research Institute

ABSTRACT

Germination response of nine commercial varieties at three different physiological ages was assessed following the dual hot water treatment (DHWT). In setts from crops of 7 and 8 months, dual hot water treatment of cuttings reduced germination as compared to the control. In 10-month setts, a beneficial effect was observed. The effect of the treatment was nonetheless variety dependent. In the profusely flowering variety M 1551/80, the initiation of bud germination prior to treatment was detrimental. Susceptibility to DHWT of top-most cuttings, which are relatively immature, particularly in the younger crops was confirmed. An increase in % germination was obtained, in many varieties, if these top-most cuttings were excluded from the germination count. Factors such as cane maturity and environmental conditions appear to be responsible for the negative impact observed on germination following hot water treatment.

Keywords: sugarcane, hot water treatment, germination, physiological age, varietal response, seedcane

INTRODUCTION

Sugar cane is vegetatively propagated through stem cuttings (three-budded setts) for the establishment of commercial fields. A healthy uniform stand is fundamental to ensure optimal yield across the whole crop cycle. Among the most important factors to be considered to achieve this goal, are germination capacity and phytosanitary status of the cuttings (Van Dillewijn 1952).

To ensure the good phytosanitary status of the crop, resort to heat therapy as a curative measure has been widely adopted. Among the different heat therapies, the most commonly used are: the short hot water treatment (SHWT: 50 ^{0}C for 30 min), for the control of chlorotic streak (Egan 1989) and smut (*Ustilago scitaminea* - Fereira and Comstock 1989), the long hot water treatment (LHWT: 50^{0}C for 2 h) for the control of ratoon stunting (*Clavibacter xyli* subsp *xyli* - Gillaspie and Teakle 1989) and the dual hot water treatment (DHWT : 50 ^{0}C for 30 min followed by 50 ^{0}C for 2 h after 24 h) for the control of gumming disease (*Xanthomonas campestris* pv *vasculorum* - Ricaud and Autrey 1989). The cold soak long hot water treatment (CSLHWT : soaking of cuttings for 48 h, followed by hot water treatment at 50 ^{o}C for 3 h) is recommended against leaf scald (*Xanthomonas albilineans* – Steindl 1971). The LHWT, DHWT, and CSLHWT are only applied to cuttings for the establishment of nurseries. These heat treatments are performed in a hot water tank.

Apart from its curative effect, the SHWT boosts up germination in most varieties. In addition, the following advantages are obtained: negligible recruiting, reduced number of cuttings per hectare, better growth and extension of the planting period (MSIRI 1954). However, the long and the dual heat treatments, which have enhanced therapeutical properties tend to reduce germination (Claus 1979; Ongoma 1992). This shortcoming impairs the proper multiplication of varieties on a commercial level and illustrates the limits of the curative treatment set by the tolerance of the seed cane to heat (Benda 1980). In Mauritius, the long hot water treatment has been used since the 1950's, primarily to obtain disease-free planting material. Later on, it was adopted prior to establishment of cane nurseries. Field observations in Mauritius, have shown that in addition to a strong intrinsic varietal influence, reaction to treatments could also be dependent on the physiological age of cuttings as reported also by Bellamy and Chinnery (1988).

The aim of this study was to investigate the germination response of nine commercial varieties to the dual hot water treatment of cuttings of different physiological ages (i.e. stalk age and cutting position along the stalk).

MATERIALS AND METHODS

Varieties and sampling sites

Nine commercial varieties (M 555/60, M 3035/55, M 1176/77, R 570, M 52/78, M 1658/78, M 1557/70, R 575 and M 1551/80) were chosen from second ratoon Mauritius Sugar Industry Research Institute (MSIRI) nurseries in 1997. Apart from M 1551/80 and R 575 obtained from Bagatelle, cuttings of other varieties were sampled from Ebene. Varieties M 52/78, M 1551/80 and R 575 are recommended for early harvest while M 1557/70 and M 1658/78 are for early to late harvest. The remaining varieties are for middle to late harvest.

Stalk age

Samples were taken at three different dates such that stalks were aged 7, 8 and 9 months for R 575 and M 1551/80 at Bagatelle and 8, 9 and 10 months for the remaining 7 varieties.

Sampling and preparation of cuttings

Forty stalks of each variety were taken at random from different stools. The stalks were cut as far as possible at ground level. They were thrashed and the green leaves removed. Damaged stalks due to borer attack or rats were discarded. Each stalk was trimmed down to the apex by removing the top tender portion. The presence of the apex was detected by splitting longitudinally the topmost part of the stalk. As far as possible, non-flowering stalks were chosen unless the variety was a profusely flowering one. Out of the 40 stalks sampled, 30 were taken and prepared as follows:

The lowest three-budded sett of the stalk was cut and labelled as the bottom-most cutting. Subsequent three budded setts were labelled as middle1, middle2, middle 3, etc. The first three-budded sett of the stalk was labelled as the topmost cutting. Any pieces of stalk remaining, between the top-most and middle cuttings (i.e., two budded or one-budded sett) were discarded.

Treatments

Cuttings from the 30 stalks received the dual hot water treatment (50 ^{0}C for 30 min on the first day followed by 50 ^{0}C for 2 h after 24 h). Cuttings were then given a cold dip treatment with fungicide Topsin M (thiophanate methyl) at a concentration of 0.6 ml/l. Cuttings from 10 stalks were kept as control. They did not receive the hot water treatment but only a cold fungicide dip as stated above.

Incubation

Following the treatment, cuttings were sandwiched, between wet gunny bags, laid on shelves in the glasshouse. The temperature and humidity were recorded by means of a thermohygrograph (Casella De Luxe model, Casella London Ltd, London). The gunny bags were kept wet for the whole duration of the experiment.

Assessment of germination

Assessment of cuttings was carried out after 4 weeks. All three buds from each cutting were assessed. A cutting was considered as germinated when at least one germinated bud with sett roots was present at the same node.

Statistical analysis

The chi-square test was performed on treated versus untreated varieties and the age effect for treated and untreated varieties (Steel 1986).

RESULTS

The temperature in the glasshouse varied between 20 ^{0}C at night and 33 ^{0}C during the day, whereas humidity varied between 68% during the day and 94% at night.

The number of 3-budded setts per stalk varied according to the variety and stalk age. Variety M 3035/66 (10 mo.) was the most productive and gave 7.1 cuttings on average in August, whilst M 1551/80 (9 mo.) was the least productive with 4.6 cuttings on average for the same month. As expected, a higher number of cuttings were obtained from older stalks. However, some varieties such as M 555/60, M 1176/77, M 1557/70, M 1551/80 and M 1658/78 had better stalk elongation than the others. In some varieties such as M 3035/66, M 52/78, R 575, and R 570, stalks chosen in August were not much longer than younger ones chosen in June and July. The variability associated with the number of cuttings for any given variety was low and the standard errors were within 0.2 hence showing the homogeneity of the plots and the sampling procedure (**Table 1**).

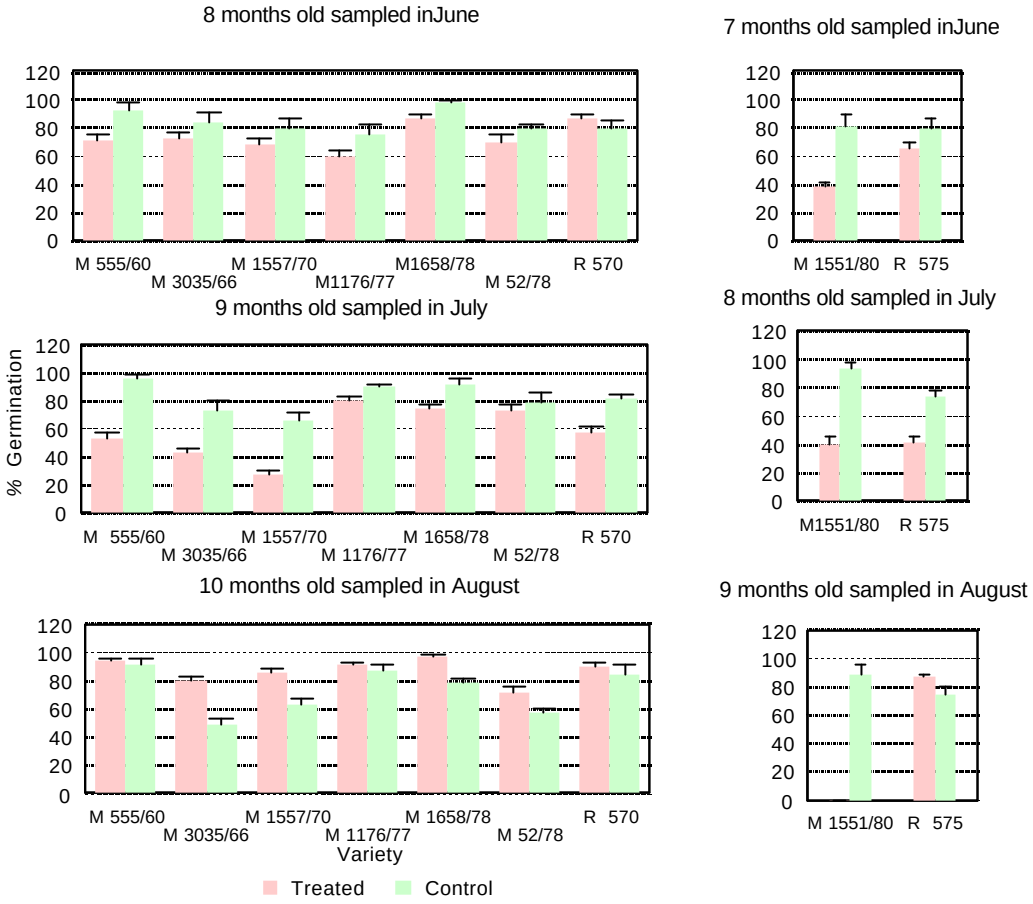
Table 1 Mean number of cuttings/stalk in nine varieties from June to August 1997

Variety	Mean number of cuttings ± S.E.		
	June	July	August
M 555/60	3.7 ± 0.1	5.3 ± 0.1	6.4 ± 0.1
M 3035/66	6.5 ± 0.2	6.5 ± 0.1	7.1 ± 0.2
M 1557/70	5.1 ± 0.1	5.9 ± 0.2	6.5 ± 0.2
M 1176/77	4.9 ± 0.2	5.9 ± 0.2	6.6 ± 0.2
M 1658/78	5.1 ± 0.1	5.3 ± 0.1	6.2 ± 0.1
M 52/78	5.1 ± 0.2	5.0 ± 0.1	5.9 ± 0.2
M 1551/80	3.4 ± 0.1	3.9 ± 0.2	4.6 ± 0.2
R 570	5.4 ± 0.2	5.6 ± 0.1	6.2 ± 0.1
R 575	4.5 ± 0.1	4.9 ± 0.1	5.3 ± 0.1

Following dual hot water treatment, the average percentage germination irrespective of varieties was highest in August (77.4%) except for M 1551/80, which did not germinate at all. Germination level was lowest in July with an average of 54%. In June, all varieties were affected by the hot water treatment (**Figure1**) except R 570. In July, germination was inferior in all treated varieties. The converse was true in August where all varieties responded well to the treatment except M 1551/80. Furthermore, in most varieties, the hot water treatment improved the homogeneity of germination such that the variability between stalks of a given variety was reduced. Significant differences ($p<0.05$) were observed on germination (as indicated by *'s on each graph of **Figure. 1**) between treated and untreated cuttings of the same varieties.

The effect of excluding the top-most or the bottom-most cuttings from the germination count showed an improved in germination level by 8% in June for varieties sampled at 8 months and by 17.4% for those sampled at 7 months. The same tendency was observed in cuttings sampled in July and August, although improvement was to a lower extent. Improved germination (+18%) in R575 in July was most evident among the 9 varieties. No significant change in germination level was noted when bottom-most cuttings were excluded in the count, except for M 1551/80, in which a reduction of 18% in June was observed (**Figure. 2**).

Figure 1 Germination response of nine varieties to dual hot water treatment



With regard to the recommended harvest period, the results showed that varieties should be harvested at the right time for the supply of planting material, particularly if they are subjected to the dual hot water treatment. On the one hand, M 1551/80 (early) could not tolerate the dual hot water treatment at the age of 9 months. On the other hand, M 1658/78 (early-late) could be harvested at all three sampling dates with appreciable germination response to the treatment whilst M 1176/77 (middle-late) responded better at 9 and 10 months.

No marked relationship was observed between the recommended harvest dates of the other varieties and germination at the three sampling dates. However, significant differences were observed on age effect of all treated varieties except M 1551/80 and M 52/78, whereas the converse was true for most of the untreated ones (**Table 2**).

In normal practice, 29 000 three-budded setts are required to plant one hectare. Based on this value, the number of stalks required for each variety can be estimated given the mean number of cuttings per variety and their corresponding mean percentage germination, the following formula has been used:

$$\text{Number of stalks required / hectare} = \frac{29\,000}{\text{(Mean number of cuttings / stalk) x (\% germination of cuttings)}}$$

From the above formula, the total number of cuttings that is required at different sampling dates was calculated (**Figure 3**). Mean number of cuttings/hectare= 28 430. In general, the number of stalks required decreased with stalk age, except when severe germination problems occurred as in M 3035/66, M 1557/70, R 570 at 9 months and R 575 (8 months) in July.

Figure 2 Effect of removing tops or bottoms on the germination percentage of nine commercial varieties at three different dates after the DHWT

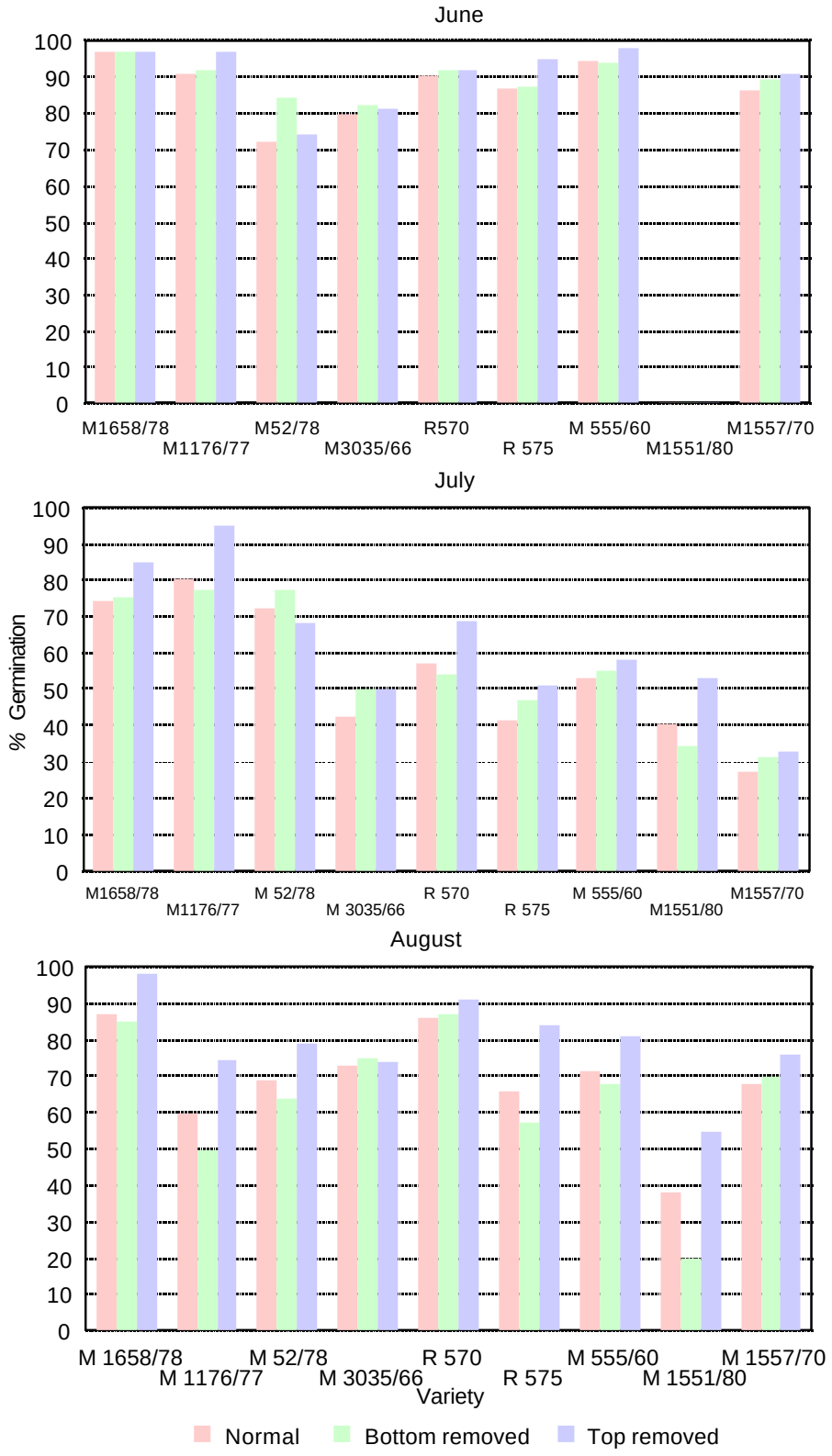


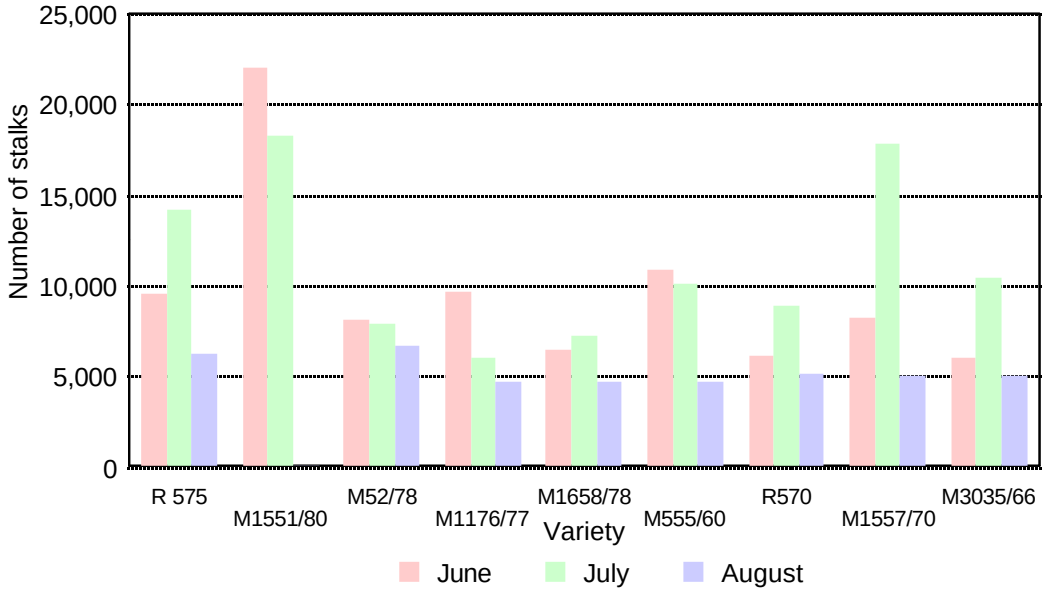
Table 2 Age effect on treated and untreated cuttings for the nine varieties

Variety	Treated		Untreated	
	8 - 9 mo	*8 - 9 mo*	*8 - 9 mo*	*8 - 9 mo*
M 555/60	S	S	N.S	N.S
M 3035/66	S	S	N.S	S
M 1557/70	S	S	N.S	N.S
M 1176/77	S	S	N.S	N.S
M 1658/78	S	S	N.S	N.S
M 52/78	N.S	N.S	N.S	S
R 570	Variety	S	N.S	N.S
	7 - 8 mo	*8 - 9 mo*	*7 - 8 mo*	*8 - 9 mo*
M 1551/80	N.S	S	N.S	N.S
R 575	S	S	N.S	N.S

S : Significant difference at 5% level of significance

N.S : No sifgnificant difference

Figure 3 Number of stalks required to plant one hectare depending on variety, stalk age and germination capacity of cuttings after DHWT



DISCUSSION

Hot water treatment tends to break bud dormancy by lowering the level of growth regulating substances and thereby weakening apical dominance (Van Dillewijn 1952). The temperature normally adopted for the treatment of sugarcane setts is 50 ^{o}C. Depending on the duration of the treatment, a beneficial or a negative effect on germination is possible. The SHWT boosts germination and is therapeutically effective against diseases. Although the long hot water treatment can be detrimental to germination (Planalsucar 1975, 1976, Claus 1979), particularly if a short pre-treatment is not carried

out before hand, it is effective in the control of a wider array of diseases. Apart from the temperature and duration of the hot water treatment, the present study confirms that varieties respond differently to the DHWT. Furthermore, the age and time at which cuttings are taken also influence the germination response.
Cuttings from all varieties had a lower germination than the untreated in June (except R 570) and July. In August, with the exception of M 1551/80, cuttings subjected to the DHWT germinated better than the control. Ongoma (1992) also found a better germination in five out of seven varieties aged 11 months after cuttings have undergone a hot water treatment of 50 ^{o}C for 2.5 h. The maturity of the setts is an important factor in supporting the heat therapy. At an advanced stage of growth, the bud scales and tissues of the embryonic shoot are more robust to withstand the heat treatment. The data obtained on germination count of topmost cuttings supports the notion that the heat treatment has a detrimental effect on the young setts. In the case of profusely flowering varieties such as M 1551/80, the buds are more prone to damage as they are no longer dormant. Stalks with bulging buds should be avoided during preparation of cuttings, as this could result in poor germination after treatment.

In contrast to what was expected if tissue maturity was the only factor governing resistance to heat treatment, an increasing germination count was not observed in the samples taken successively in June, July and August. It would appear that other factors, possibly climatic conditions, could also be responsible in determining the susceptibility of the setts to heat shock. Anderson and Dusky (1986) showed that temperature brought about a reduction in germination. At 15.6 ^{o}C, percentage germination was half that when the temperature was 26.7 ^{o}C. It is speculated that at low temperatures, an increase in the production of hormones such as gibberellic acid by the plant could induce a delay in germination of cuttings. This growth compound is known to inhibit bud germination in sugarcane (Anderson and Dusky 1986) and this effect could possibly be present despite the heat treatment. Physiological differences in the initial level of assimilates of genotypes can also be responsible for their germination capacity. A positive correlation has been found between germination and sett moisture, reducing sugars as well as gums. In contrast, brix and soluble proteins were negatively correlated (Singh and Kanwar 1986).

The germination capacity of sugarcane cuttings appears to be governed by a complexity of interacting factors that has not been fully elucidated. The treatment of the setts in hot water brings in another element that further complicates this issue. Information on the germination process is vital to ensure uniform establishment of seed and commercial fields and avoid costly recruiting and yield losses.

CONCLUSIONS

For each variety and at different sampling points, the number of stalks required to plant a given area could be more readily estimated, if and only if the mean number of cuttings per stalk and the corresponding germination % following the DHWT were known beforehand. Such information would be useful to ensure an even stand and prevent the eventual cost of recruiting or replanting. Furthermore, with the additional information on stalk density, a good estimation would ensure that the right acreage would be planted for the adequate supply of cuttings.

Although each variety should be considered on an individual basis as regard to its germination response following the DHWT, it can be concluded that stalks of 10 months are most appropriate to withstand the heat shock. However, particular attention should be given to profusely flowering varieties in which the loss of top dominance could initiate the germination of topmost buds and hence, lower their resistance to the treatment. It would be useful to compile such information for existing commercial varieties, newly released ones as well as promising clones.

ACKNOWLEDGEMENTS

The authors thank the Director and Deputy Director (Biology) for their support and permission to publish this paper. The contribution of Mr H. Medan is gratefully acknowledged.

REFERENCES

ANDERSON DL and DUSKY JA. 1986. Mathematical model interpretation of sugarcane bud germination. *Sugar Cane* No.6: 6-10.

BELLAMY SR and CHINNERY LE. 1988. The effect of bud age on germination in sugar cane and two related species. *Sugar Cane*. p 12-14.

BENDA GTA. 1980. Hot-water treatment and sugar cane health. *Sugar Journal*. 43:5. p 22.

CLAUS R. 1979. The influence of heat treatment on eight sugar cane varieties. *AgronomieTropicale*. 34:2. p 122-126.

EGAN BT. 1989. Chlorotic streak. p 247-256. *In* Ricaud C, Egan B.T, Gillaspie Jr A.G and Hughes C.G. eds. *Diseases of sugar cane. Major diseases*. Amsterdam, Elsevier Science Publishers B.V.

FERREIRA SA and COMSTOCK JC. 1989. Smut. p 211-224. *In* Ricaud C, Egan B.T, Gillaspie Jr A.G and Hughes C.G. 1989. eds. *Diseases of sugar cane. Major diseases*. Amsterdam, Elsevier Science Publishers B.V.

GILLASPIE JR AG and TEAKLE DS. 1989. Ratoon stunting disease. p 59-74. *In* Ricaud C, Egan B.T, Gillaspie Jr A.G and Hughes C.G. eds. *Diseases of sugar cane. Major diseases*. Amsterdam, Elsevier Science Publishers B.V.

ONGOMA GIB. 1992. Effect of hot water treatment on the germination of some east African sugar cane varieties. *Proc. South African Sugar Tech. Assoc*. 66th annual congress. p 87-88.

PLANALSUCAR. 1975. Effect of the long hot water treatment on the germination of sugar cane. *Annual report* 1975. p 38-39.

PLANALSUCAR. 1976. Tolerance of sugar cane varieties to long hot water treatment. *Annual report* 1976. p 31-32.

RICAUD C and AUTREY LJC. 1989. Gumming disease. p 21-33. *In* Ricaud C, Egan B.T, Gillaspie Jr A.G and Hughes C.G. eds. *Diseases of sugar cane. Major diseases*. Amsterdam, Elsevier Science Publishers B.V.

SINGH O and KANWAR RS. 1986. Association of cane sett assimilates with germination. *Sugar Cane* No. 2: 7-10.

STEEL RGD and TORRIE JH. 1986. *Principles and procedures of statistics. A Biometrical App*roach. 2nd ed. p 477-494

STEINDL DRL. 1971. The elimination of leaf scald from infected plant material. *Proc. ISSCT* 14: p 925-929.

VAN DILLEWIJN. 1952 . Physiology: Germination. p 59-76. *In* Van Dillewijn. ed. *Botany of Sugarcane*. Waltham Mass. USA.

PRODUCTION OF EARLY ONION CROP FROM SETS : EFFECTS OF AGE AND SIZE OF SET ON BULB YIELD AND QUALITY

S Seetohul **and** *P Hanoomanjee*

Agricultural Research and Extension Unit

ABSTRACT

In an attempt to produce an early crop of onion through the use of sets, a project was initiated in 1997 with a view to identifying suitable cultivars and to determining the optimal set characteristics for raising the crop. The performance of seven cultivars was compared to the commercial variety, namely Local Red and results showed that cultivar Star 5504 was the most promising one, producing a marketable bulb yield of 28.25 tha^{-1} and a low level of splitting (3.20%).

The effect of 3 set ages (namely 4, 8 and 14 weeks) and 3 set sizes (namely 5-10 mm, 11-15 mm, 16-20 mm bulb diameter) of 4 cultivars (namely Yellow Dessex, Sivan, Veronique and Local red) on bulb yield and quality was also investigated. Results indicated that the optimal set characteristics, assessed on the basis of crop establishment, marketable bulb yield amount of split and thick necked bulbs differed with variety. With cultivar Local Red, the best performance was achieved with set age of 4 weeks and set size of 5-10 mm. With cultivar Veronique, sets of the age of 8 weeks and of size of 16-20 mm were found to be better. For cultivar Yellow Dessex the best performance was obtained at sets age of 14 weeks and sets size of 16-20 mm and for Sivan, sets of 8 weeks and set size of 11-15 mm produced the best yield.

Keywords : onions, sets, ages, size, variety trials, yields

INTRODUCTION

In Mauritius, about 6000 tonnes of onion are produced annually over an area of 320 to 340 hectares. The bulk of the crop is raised from seeds and it is estimated that about 10 per cent of the local production is derived from sets. The production of onion from sets has traditionally been performed in the coastal regions of Belle Mare, Palmar, Trou d'eau Douce, Grand Sable, Petit Sable, and to a minor extent in a few scattered localities like Bassin, Palma, La Chaumière, Saint Martin and Plaisance.

Brewster (1994) described sets as small onion bulbs, ranging from 2g to 3g in fresh weight. They are produced by growing a crop from seed sown at a high population density of 1000 to 2000 plants per m^2. Sets are less than 25 mm in diameter and are planted to develop into larger bulbs. Owing to their size, sets produce a more robust plant at emergence as compared to seeds. This allows them to be grown successfully in less favourable growing conditions where the use of transplant and direct sowing are limited. Sets have a shorter growing season than plants from seeds and this advantage is often exploited when a rapid or early season production is required. In fact it is possible to advance the crop by some 3 weeks when sets are used to raise a crop as compared to direct sowing (O'connor 1994).

The use of sets in onion production is particularly useful for extending the availability of the commodity throughout the season. In Norway, large sets (up to 20 mm in diameter) are used to produce early bulb. Sets that are less than 16 mm in diameter rarely flower. However one disadvantage of large sets is their tendency to bolt, particularly if exposed for long periods to cool temperatures (7-12^o C) before they start to bulb. Also large sets are reported to produce higher amount of split bulbs (Brewster 1994)

In Mauritius, the production of onion from sets is carried out in a two-stage process. In the initial stage, onion seeds are either sown in bands or broadcast on raised beds in the month of September. After emergence, the seedlings undergo a short vegetative phase and when favoured by the prevailing conditions of increasing day-length and temperature, bulbification occurs to produce sets. The sets are harvested usually in November after a cycle of 70 to 90 days and are usually kept under ambient storage. In the second stage, the sets which are locally referred to as "march sets" are sown on raised beds in the month of March for the commercial production of new onion crops which may be harvested after a crop cycle of about 12 weeks.

To date the commercial production of sets has been restricted to only one cultivar, namely the Local Red which can produce a bulb yield of 10 to 12 t ha $^{-1}$. In 1996, preliminary trials were conducted by the Agricultural Research and Extension Unit at the Richelieu and the Réduit Crop Research Stations and results have shown that onion bulb yield of 20 to 25 t ha $^{-1}$ could be achieved through the use of sets of high yielding cultivars. Moreover the crop could be harvested as from June, a period when the country depends on imported onions to satisfy the local demand. This clearly indicates the potential of sets for producing an early onion crop.

In this respect, a research project was started in 1997 with a view to assessing the potential use of sets for early onion production. The project consisted of two distinct components. Primo, field trials were conducted to identify suitable onion cultivars that are more adapted for bulb production from sets. Secundo, the investigation focused on the determination of optimal set characteristics (age and size) for 4 cultivars that produced promising results in earlier trials.

MATERIALS AND METHODS

Identification of cultivars suitable for set production

One field trial was performed at the Richelieu Crop Research Station. Sets of 7 onion cultivars namely Sivan, BGS 82, Yellow Dessex, Veronique, Star 5504, Agrifound Light Red and Agrifound Dark Red were evaluated and compared with the Local Red Onion variety as control. The trial was set up using a Randomized Complete Block Design with 4 replicates and plot size of 3 m^2. The sets (180 per plot) were sown at a spacing of 10 cm x 15 cm on the 23rd of March 1998 and onion bulbs were harvested on the 28th of July. All treatments were subjected to the standard cultural practices (AREU 1997). The performance of the cultivars was assessed on the following parameters namely the total and marketable bulb yield and the amount of split and thick-necks.

Determination of optimal set age and size

Sets of three ages (namely 4, 8 and 14 week old) and three sizes (namely small, 5-10 mm, medium 11-15 mm and large 16-20 mm in diameter) of four onion cultivars namely Yellow Dessex, Sivan, Veronique and Local Red were used for the study. The sets were obtained by sowing the onion seeds at different sowing densities of 19, 27 and 50 gm^{-2} and on varying dates (namely 4/9, 7/10 and 17/10/97 respectively) at the Réduit Crop Research Station. This factorial experiment was started on the 3rd of February 1998 and the treatments were laid out in a completely randomised block design with 4 replicates. The sets were sown at a spacing of 10 x 15 cm on plot size of 3 m^2 and onion bulbs were harvested on the 3rd of June 1997. All treatments were subjected to standard cultural practices. The following parameters were measured: crop establishment (27 days after planting), total and marketable bulb yield, amount of split bulbs and thick necked bulbs.

RESULTS

The results of the variety trial conducted at the Richelieu Crop Research Station are presented **Table 1**. Statistical analysis revealed that there were significant differences among the varieties with respect to all the four parameters observed, namely total yield, marketable yield, split and thick neck.

Table 1 Average performance of onion cultivars under test at Richelieu

Cultivars	Total yield	Marketable yield		Split		Thick necks	
	t ha^{-1}	*t ha^{-1}*	*%*	*t ha^{-1}*	*%*	*t ha^{-1}*	*%*
Star 5504	29.82^{a}	28.25^{d}	94.7	0.95 ^{d}	3.2	0.62^{c}	2.1
Sivan	26.80^{ab}	21.00^{a}	78.2	3.04^{cd}	11.4	2.75^{a}	10.3
Yellow Dessex	20.90^{bc}	18.50^{d}	88.6	1.10 ^{d}	5.2	1.30^{c}	6.2
BGS 82	20.10^{c}	11.50^{ab}	57.3	8.05^{a}	40.0	0.55^{b}	2.7
Agrifound Light Red	19.35^{cd}	11.55^{d}	59.7	7.00^{ab}	36.2	0.80^{c}	4.1
Agrifound Dark Red	17.90^{cd}	10.35^{d}	57.9	6.85^{ab}	38.2	0.70^{c}	3.9
Local Red	14.10^{d}	8.75^{bc}	62.0	4.90^{bc}	34.8	0.45^{b}	3.2
Veronique	13.85^{d}	11.00^{d}	79.5	2.30^{cd}	16.6	0.55^{c}	3.9
S.E ±	1.82	1.58		0.78		0.17	

It was observed that all the seven varieties performed better than the local variety with respect to both the total and marketable yields. The highest total bulb yield was obtained from the cultivar Star 5504 (29.82 t ha^{-1}) followed by cultivar Sivan (26.90 t ha^{-1}) and Yellow Dessex (20.90 t ha^{-1}) and the lowest yields were recorded in the cultivars Veronique (13.85 t ha^{-1}) and Local Red (14.1 t ha^{-1}) respectively. A similar trend was observed with respect to marketable yield. High levels of splits and thick necks in onion bulb are considered as undesirable traits which render the bulbs non marketable. Results showed that in Local Red, the percentage split and percentage thickneck bulbs were 34.8% and 3.2% respectively. Three cultivars, namely Star 5504, Yellow Dessex and Sivan, had significantly lower % split, ranging from 3.2 to 11.4 %. On the other hand, only 2 cultivars namely Star 5504 and BGS were found to have a thickneck % lower than Local Red.

Influence of age and size of set

Crop establishment

The crop establishment was assessed after 27 days of planting and the results are shown in **Figure.1**. Significant differences in percentage emergence were noted among the treatments. Irrespective of variety and size, sets of 4 weeks old produced very low emergence (less than 50%) and are therefore unsuitable for raising a successful crop. Sets of 8 weeks old of only two cultivars (namely Veronique and Sivan) produced satisfactory levels of emergence (80%), but only when large sized sets were used. Older (14 weeks) and larger sized sets produced above 80% establishment for all the varieties.

Bulb yield

Irrespective of variety and age of set, a total bulb yields were significantly higher when large sized sets were used. Highest yields were however obtained with sets that were both large and old. It will be observed that cultivar Yellow Dessex was the highest yielding variety, followed by cultivar Veronique (**Figure 2).** The use of small sized sets resulted in significantly lower bulb yields, except for cultivar Veronique when sets of 4 and 8 weeks old were used. Yield reduction associated with small set was highest (more than threefold) in cultivar Yellow Dessex. Local Red cultivar produced the best yield when large sized sets of 8 weeks old were used. Varieties differed significantly with respect of the percentage of marketable bulbs produced. Although older sets produced the higher total bulb yields, the percentage of non-marketable bulbs was also the lowest. In fact, higher percentages of marketable yield (above 85%) were produced when sets of 8 weeks old were used. Another striking observation is the very low percentage of marketable yield recorded for cultivar Local Red (< 14%) when old sets were used.

Figure 1 Crop establishment of different cultivars of onion after 27 days

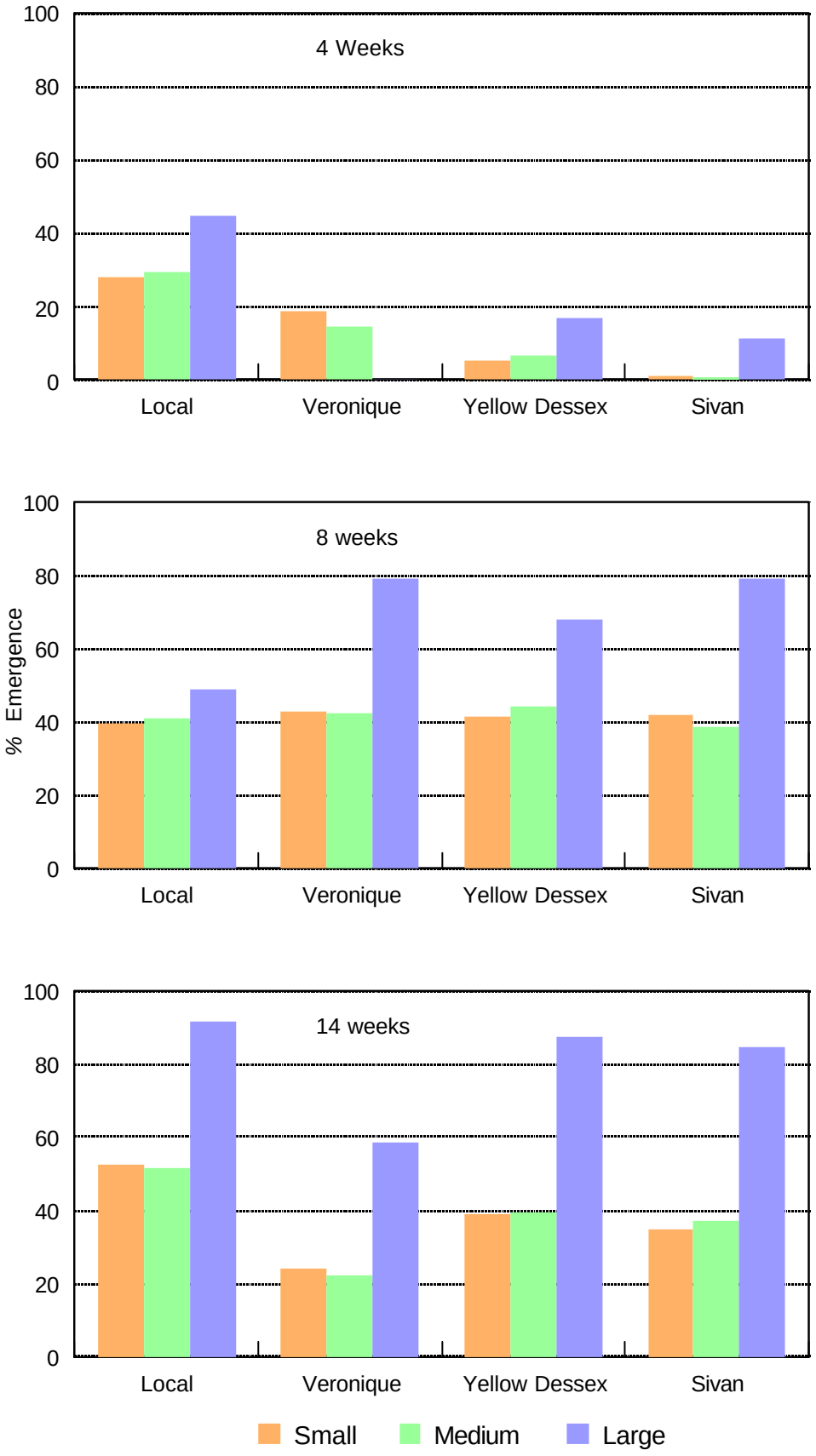
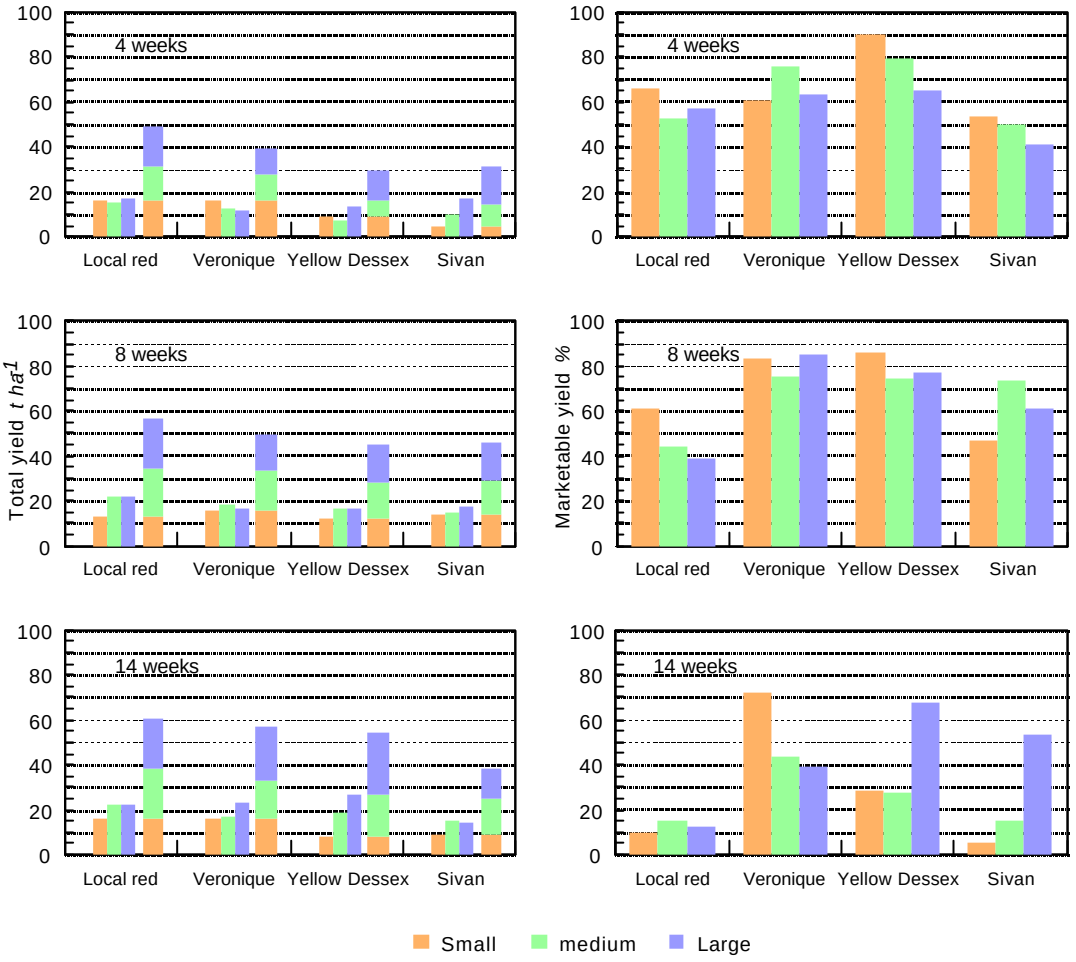


Figure 2 Total yield and marketable yield %



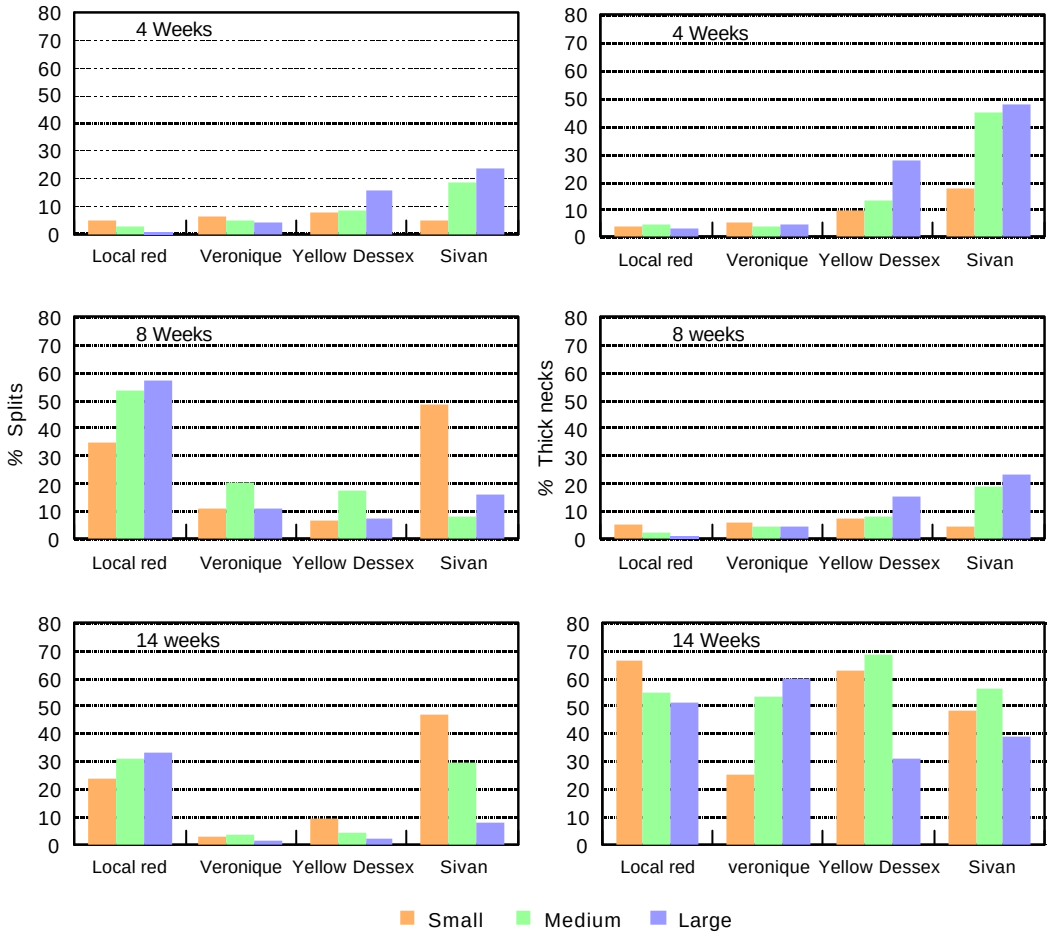
Bulb Quality

Non marketable bulbs are of poor quality, which is characterised by high levels of splits and thick neck. The percentage of splits and thick necked bulbs differed significantly with cultivar, set age and size.

Two cultivars, namely Local Red and Sivan, were found to produce the largest amount of non marketable bulbs. The Local Red cultivar produced the highest levels of splits and thick necked bulb, especially when the crop was raised with small sized sets of 14 weeks old. Highest quality (i.e. lowest % split and % thick neck) was obtained with cultivar Yellow Dessex, especially when sets of 4 to 8 weeks were used. (**Figure 3)**

In general, irrespective of variety, higher levels of split and thick necked bulbs were obtained when sets of 14 weeks old, especially of larger size, were grown. Sets of 8 weeks old produced bulbs with the lowest level of thick neck whereas the use sets of 14 week old resulted in the lowest level of splits.

Figure 3 Percentage splits and thick necks



DISCUSSION

The use of sets for producing an early crop of onion has been very popular among farmers in the East and the South East. It has however been observed that there has been a gradual disinterest to use sets and one reason that accounted for this disinterest was the poor yield of the crop and the high percentage of non-marketable bulb. It is relevant to point out here that only one variety was grown, namely the local Red and hence the yield of this variety was not considered profitable enough.

Our study shows that both total and marketable yield of onion produced from sets can be significantly increased. One variety, more specifically Star 5504 produced total bulb yields that was double that of Local Red and with almost 95% marketable bulbs (unlike 62% from local Red variety). Two other varieties (Sivan and Yellow Dessex) also would be of significant benefit to onion growers. The adoption of these varieties will no doubt improve the production and revenue of farmers.

Another reason that would explain the gradual loss of interest in using set for onion production is probably associated with the poor set quality. Brewster (1994) indicated that the major constraint linked with set use is the susceptibility of some cultivars to bold and to produce splits and thicker bulbs, and their ability in breaking seed dormancy which results in poor or delayed emergence. This is particularly important as farmers produce their own sets, which are of variable sizes and ages.

Results have clearly indicated that only large sets, which are about 14 weeks, are suitable for successful crop establishment. Sets of less than 14 weeks old can only be considered in selected varieties, but even

here large set should be adopted. Elsewhere, the use of young sets has not been recommended as this results in poor emergence because of dormancy.

The importance of using set of the desirable characteristics was clearly highlighted in this study. The two factors that were investigated, namely set size and set age, did influence both the bulb yield and the bulb quality. It was observed that sets of 14 weeks old not only produced the highest total bulb yield but also significantly higher percentage of thick necked bulb. Similar observations were reported by Madisa (1994) and Farag and Koriem (1990). On the other hand, splits are more commonly obtained when younger sets are used especially if the set size is large. Varieties differed not only in terms of bulb yield potential but also with bulb quality. Cultivar Yellow Dessex appeared to be most promising.

ACKNOWLEDGEMENT

We wish to thank the Station Manager and staff for facilities and field support and Mr R Ramnauth for assistance provided to analyse the experimental data.

REFERENCES

BREWSTER JL. 1994. *Onions and other Vegetables Alliums*. pp. 109 - 110.

O'CONNOR DE. 1994. Use of onion sets to aid continuity in bulb onion production. *Acta Horticulturae* 371

FARAG IA and KORIEM SO. 1990. Effect of nitrogen fertiliser spacing and size of sets on growth, yield and quality of onion. *Egyptian Journal of Agricultural Research* (21), 1-90.

MADISA E. 1994. The effect of Planting date, set size and spacing on the yield of onion (*Allium cepa*). *Acta Horticulturae* 358

AREU 1997 *see under* Agricultural Research and Extension Unit

AGRICULTURAL RESEARCH AND EXTENSION UNIT. 1997. *Guide Agricole*. Réduit, AREU.

INFLUENCE OF FRESH AND COLD STORED PLANTLETS ON STRAWBERRY YIELD

B Lutchoomun

Agricultural Research and Extension Unit

ABSTRACT

This experiment aimed at comparing the effect of locally produced fresh and imported cold stored plantlets of strawberry (var Mara des Bois) on yield and fruit quality. Imported cold stored plantlets had more vigorous vegetative growth, were early bearing and produced higher yield and better quality fruits than locally produced fresh plantlets.

Key words: strawberries, fresh runners, cold stored plantlets, fruit quality, yield

INTRODUCTION

Strawberry, highly priced for its delicious fruits, is one of the most important soft fruits of the world. Introduced in late 1950's, it is a relatively new crop in Mauritius and is presently commercially grown on a small scale in the humid and super humid regions. It is propagated vegetatively using fresh plantlets (runners) or cold stored plantlets (frigo plants). Commercial strawberry growers around the world have a preference for cold stored plantlets over freshly rooted runners due to its associated advantages, in particular improved yields and flexibility in planting date (Roudeillac and Veschambre 1987). In this context, the objective of research was to compare the agronomic and yield performance of the two types of planting materials, cold stored plantlets and fresh runners, and determine which planting material would be more economic on a commercial scale in Mauritius.

MATERIALS AND METHODS

The experiment was conducted at Curepipe Experiment Station using a randomised complete block design with four replicates and 30 plants per plot of size 2.7 m^2. The two treatments were cold stored plantlets **(Plate 1**) and fresh runners (**Plate 2**) of the day neutral strawberry variety Mara des Bois. The 4½months old fresh runners were obtained locally from the Nursery at Curepipe Experiment Station for immediate planting. Certified (1½year old) cold stored plantlets were obtained from the nursery Marionnet (France) and were stored at 4 ^{o}C for 2 weeks prior to planting. The cold stored planters had no mature green leaves at planting whereas fresh runners had an average of 4 mature and healthy dark green leaves per plant. However, it was observed that the root system in frigo plants was longer by three times and was denser than that of fresh runners (**Plate 3**).

Plate 1 Cold stored plantlets

Plate 2 Fresh runners

Plate 3 Frigo plants

Pale yellowish immature leaves were visible in frigo plants, which were sprouting. The fresh and cold stored plantlets were transplanted under plastic tunnel 2.1 m high on 14th of April 1997 on drip-irrigated beds mulched with black plastic. Recruiting was effected within 3 weeks after transplanting.

Deblossoming was practised after transplantation for one month to promote plant establishment. Old and diseased leaves were removed regularly to improve field sanitation and a net was placed over the tunnels to protect fruits from bird damage.

Harvest started in both treatments in the third week of June to end in the last week of December 1997. Three quarter to full ripe fruits were harvested three times weekly.

The following parameters were observed for evaluation of the two types of planting material:

Plant recruitment per plot and per treatment

Diameter of canopy (cm), height of plant (cm) and the number of crowns and leaves per plant two months after transplanting.

Date of harvest

Total and marketable yields per plot. Non-marketable were considered as fruits which were off-typed, bruised, damaged by pests or diseases or weighed less than 3g each.

Average of large (> 15 g), medium (6-15 g) and small (< 6g) size of marketable fruits.

RESULTS

Plant development

Plant recruitment effected within three weeks after transplanting was 0.8% in cold stored plantlets and 18.3% in fresh runners. Development was more vigorous in cold stored plantlets and, two months after planting, produced canopy three times larger and twice taller than that produced by fresh runners (**Table 1**). In addition, cold stored plantlets had three times more crowns and two and a half times more leaves than fresh runners at flowering and start of fruiting season.

Table 1 Vegetative plant development two months after transplanting

Plant type	Diameter of canopy *cm*	Plant height *cm*	Number of crowns per plant	Number of leaves per plant
Cold stored	30	10	3	20
Fresh	10	5	1	8
SE ±	0.2	0.3	0.2	0.6

Yield and yield parameters

Cold stored plantlets produced more than 2½times higher total and marketable yields than fresh runners (**Table2**). Marketable yields exceeded 80% of total yield in both treatments. However, there was no significant difference in average fruit weight among treatments.

Table 2 Average yields, fruit weight and proportion of diseased fruits

Plant type	Total yield $t\ ha^{-1}$	Marketable yield $t\ ha^{-1}$	Average fruit weight *g*
Cold stored	25.9	21.5	6.6
Fresh	9.7	7.9	6.0
SE ±	0.7	1.0	0.2

Furthermore, cold stored plantlets produced more than twice the proportion of large size and 8% more medium size fruits than fresh runners (**Table 3**).

Table 3 Proportion of fruit grades

Plant type	Large %	Medium %	Small %
Cold stored	9	57	34
Fresh	4	49	47

On the other hand, the proportion of small fruit was high among fresh runners. In addition, frigo plants attained midharvest period 219 days after transplanting and were two weeks earlier than fresh runners.

DISCUSSION

Frigo plants of the variety Mara des Bois had longer and denser root system than the fresh runners, indicating presence of accumulated food reserves and enhanced development of the planting material. Development of the planting materials is influenced by climatic conditions.

Various steps are involved in the production of frigo plants, which ultimately determine the quality of the propagation material. Runner formation starts under long day length and warm day conditions in summer in temperate, tropical or subtropical countries. However, in temperate countries, when the temperature drops to below 15^{o}C in autumn, the plant metabolic activities slow down and carbohydrate reserves are accumulated in the rhizomes and roots of the plantlets while leaf development is reduced. The plant thus becomes relatively vegetatively dormant and flowering is induced. In winter, under short day-length and low temperature (< 5^{o}C) conditions, floral initiation and vegetative growth is stopped completely. Growth then resumes in spring under warm temperature conditions, eventually resulting in flowering and fruiting. Since 1950's, however, storage at -2 ^{o}C of 9-11 months old strawberry plantlets is practiced in temperate countries after defoliation of the runners in end autumn or in winter. These plantlets are completely dormant, multi-crowned and possess long roots exceeding 15cm.

The reserves in frigoplants seem to be mobilised quickly after transplantation, as pointed out by Roudeillac and Veschambre (1987) so that these plantlets produce new leaves in few days after planting. Thus, plant establishment was better in presence of well-developed root system and high food reserves, resulting in very low level of recruiting (< 1%). Plant development was more vigorous in presence of multicrowns, producing more leaves and a taller and larger leaf canopy than fresh runners. The early and fast plant establishment, accompanied with the availability of stored assimilates might have induced crop vigour, as also reported by Froli (1985), and hastened and improved plant canopy development in frigoplants.

Under our local conditions, the runners produced from mother plants never attain dormancy due to the warm conditions prevailing throughout the year. The day temperature does not fall below 15^{o}C and the 4.5 months old runners are actively growing, with little reserves when uprooted for transplantation at the end of summer season in April (Anon 1981, 1985) to eventually produce flowers and fruits in winter.

The fresh runners of the variety Mara des Bois that were separated from the mother plant in 4½months had more functional leaves but a relatively less developed root system than frigo plants at planting. At the time of runner selection, the runners were going through an active vegetative growth with a low level of stored metabolites. Consequently, when planted such runners with limited assimilates and poor root system go through a phase of re-adaptation using mostly current assimilates from the few leaves present for growth. Thus, compared to frigo plants, plant mortality was relatively high in fresh runners resulting in higher proportion of recruitment (18.3%) than frigo plants, and a delay in both plant establishment and further canopy development.

The well-developed leaf canopy of frigo plants and the higher number of total functional leaves at flowering and start of production offered a much larger photosynthetic area than the fresh runners. Moreover, light penetration could have probably been also improved as the cold stored runners were more than twice taller and less compact than fresh runners. Consequently, during fruit development, the

frigo plants had more available assimilates for optimum development of the fruits than fresh runners. Thus, both total (25.9 v/s 9.7 t/ha) and marketable yields (21.5 v/s 7.9 t/ha) were highly improved in case of frigo plants as compared to fresh. In addition, although the proportion of marketable yields were similar in both treatments, it is the high marketable yield by weight and the improved proportion of large and medium size fruits that show the superiority of using frigo plants in commercial production.

The increases in yield using frigo plants was also associated to the attainment of midharvest period 2 weeks earlier than that in fresh runners. Previous trials carried on strawberry using the promising variety Marquise showed an average total yield of 687 g/plant with frigo plants (Anon 1994) and was more than 2½times higher than fresh runners, which yielded 255 g fruits per plant (Anon 1997). Turemis et al. (1997) and Economides and Gregariou (1988) have respectively reported improved yield and earliness when using frigo plants.

The additional cost in production due to use of frigo plants as compared to use of locally produced fresh runners is MUR 23 400 for an area of 0.46 ha (3000 plants). The increase in yield is 630 kg and represents additional revenue of MUR 52 200, which indicates an additional profit of MUR 28 800 **table 4.**

Table 4 Income obtained from cultivation of 3 000 plants of strawberry var Mara des Bois

Type of plantlet	Expected marketable yield	Revenue from sale of fruit (@MUR 120 / *kg*)	Revenue cost of plant
Fresh	363 kg	MUR 43 560	MUR 40 560
Frigo	993 kg	MUR 119 160	MUR 92 760

FOB Price of other varieties available at nursery J. Marionnet varies between 0.68 FRF - 0.88 FRF (J. Marionnet, Pers. Comm.).

Price fresh runners: MUR 3 000 (@MUR 1.00 / plant)

Price frigo plants (FOB) = 3 600 FRF (@ 1.20 FRF / plant)

Freight = 3 000 FRF

FOB + Freight = 6 600 FRF (equals to MUR 26 400 (@ 1 FRF = MUR 4.00)

Improvement in vegetative plant development, improvement in yield and quality of strawberry fruit associated with earliness in production and increase in profitability indicate the number of advantages associated in using frigo plantlets as compared to fresh runners in commercial strawberry production.

CONCLUSION

Cold stored plantlets of the variety Mara des Bois had a better canopy and more crowns resulting in much improved total (25.9 v/s 9.7 t ha^{-1}) and marketable (21.5 v/s 7.9 t ha^{-1}) yields than fresh runners. Moreover, cold stored plantlets had higher proportions of large and medium size fruits and attained midharvest two weeks earlier than fresh runners. Thus, it can be deduced that cultivation of cold stored plantlets from reputable sources may be one method of increasing local production of strawberry.

REFERENCES

ANON. 1981. Planting date trial using var C. Favourite. *Ann. Rep Ministry of Agriculture and Natural Resources, Mauritius.*

ANON. 1985. Multiplication x spacing trial var Tiobelle. *Ann. Rep Ministry of Agriculture and Natural Resources, Mauritius.*

ANON. 1994. *Ann. Rep. Directorate of Agricultural Research and Extension Unit (DARE), Min. Agric. Nat. Res., Mauritius.*

ANON. 1996. Comparison of production systems and varietal evaluation of strawberry. *Ann. Rep Agricultural Research and Extension Unit, Mauritius.*

ECONOMIDES CV, GREGARIOU C. 1988. *Strawberry variety trials under cover and in the open field using fresh and frigo plants*. Agric. Res. Inst.' Nicosia Cyprus. SP.

FROLI S. 1995. *Les petit fruits*. P 43.

ROUDEILLAC R, VESCHAMBRE D. 1987. *La Fraise*. Paris. France: CTIFL-CIREF, 182-183p

TUMERIS N et al. 1997. Comparison of yield and quality of strawberry cultivars using frigo plants and fresh runners rooted in pots. Proceedings of the third international strawberry symposium. vol 2. *Acta-Hort* No. 439: 537-542p.

POST-HARVEST QUALITY IMPROVEMENT OF BANANA

I Ramma, SP Beni Madhu **and** *P Peerthum*

Agricultural Research and Extension Unit

ABSTRACT

Studies carried out from 1996 to 1998 revealed that the best maturity index for determining the harvest time of banana is a combination of bunch age and finger diameter. However, the bunch age and finger diameter ranges for indicating optimum harvest maturity stage have to be worked out for each of the economically important banana varieties.

In a survey of local markets, crown rot was identified as the major postharvest disease. Fungicide trial showed that thiabendazole at the rate of 500 and 1000 ppm and benomyl at the rate of 250 and 500 ppm used as post harvest dip successfully controlled the disease with a more persistent control with the higher dosages. Industrially ripened fruits had the longest shelf life of 8 days when stored at 18°C as compared to 7 days when stored at ambient room conditions and 4 days when stored under simulated warm market conditions.

Keywords: bananas, *Musa* spp., shelf life, maturity index, finger diameter, bunch age, post harvest diseases, harvest, storage, fruit quality.

INTRODUCTION

Banana, one of major fruits in Mauritius, has now moved from backyard to commercial production, with an annual production of 9,000 tonnes for the local market. However, banana being a delicate and highly perishable fruit, the local production is subjected to serious post harvest losses, mainly due to harvesting at improper maturity stage, poor handling and storage practices and post harvest diseases. Research was undertaken within a project, partially funded by the Mauritius Research Council, to address these issues so as to improve the post harvest quality of banana. This paper outlines activities undertaken within the project from 1996 to 1998 related to determination of optimum harvest maturity index, the disease status of banana on the local market and the effects of different storage conditions on fruit quality.

MATERIALS AND METHODS

Details of activities conducted are described hereunder.

Determination of an optimum harvest maturity index

Trial Sites

Trials were laid out in already existing orchards of Wooton Experiment Station and on the premises of Médine and Britannia Sugar Estates. At Médine S. E, a trial was conducted on banana cultivar Dwarf Cavendish over 2 seasons (winter and summer (1997/1998), while at Médine and Britannia Sugar Estates, trials were carried out on the banana cultivar Williams during the period of February/March 1997 to July/August 1997.

For all sites, banana bunches were tagged at the time of flower emergence (shooting) and the date of flower emergence of each plant was recorded so as to calculate the physiological age of the bunch at the time of harvest. Five randomly selected banana bunches of each of the different physiological ages studied were harvested at the same time, dehanded and the following parameters were measured:

Mean fruit weight = (*(Weight of bunch - weight of stalk) / total no. of fingers*)

Length of finger (external curvature) using banana finger gauge

Diameter of a predetermined finger using vernier caliper (*the middle outermost finger of the second hand from the proximal end of the bunch*)

Pulp : peel ratio (*calculated as the mean (weight of peel / weight of pulp) of 10 individual fingers were taken randomly from each bunch*

Effect of bunch harvest age on shelf life and quality of banana

Five randomly selected bunches at 4 harvest ages (12, 14, 16 and 18 weeks old) were harvested from already existing banana c.v.Williams plantation at Anna, Flic-en Flac. Each bunch was dehanded and diameter of predetermined finger was recorded. Clusters of 6 fruits each from the 2nd and 3rd hands from the proximal end were selected from each bunch. 5 clusters from each harvest age were subjected to industrial ripening and then stored at ambient conditions. Each treatment was replicated 4 times. The fruits were scored for their peel colour daily and 5 randomly selected fruits (1 from each cluster) were assessed for the pulp bricks at colour score 6. The shelf life of the fruits was determined by calculating the number of days between the commencement of ripening determined by first sign of change in fruit peel colour and end of saleable life (corresponding to colour score 7).

Appraisal, identification and control of major post-harvest diseases on banana

A survey of 8 pre-identified markets situated in different localities were conducted on 8 different occasions over the period of June - October 1996 and April - August 1997 to identify the major post harvest diseases and their causal organisms. The markets were visited at monthly intervals and at each sale point a random sample of 4 hands was collected and kept in polyethylene bags at the Plant Pathology Laboratory for isolation of pathogen(s) and identification.

The banana hands were kept in the laboratory and observations and isolations were made at regular intervals from the advancing margins of the diseases on the crown and the fruits. Diseased tissues were plated on standard potato dextrose agar and the micro organisms were allowed to grow at room temperature for three to five days. Identification of fungi was carried out in the laboratory using a light microscope.

Following the survey on disease status of banana, a fungicide evaluation trial was conducted to control the major disease (crown rot) on banana c.v. Dwarf Cavendish. Fruits were harvested at uniform maturity and were treated by dipping for 2 minutes in the following solutions:

thiabendazole (Mertect 20S TBZ)	@ 500 and 1000 ppm,
benomyl (Benlate 250)	@ 250 and 500 ppm,
chlorothalonil (Bravo 500)	@ 500 and 1000 ppm and
prochloraz (Sportak 40)	@ 500 and 1000 ppm
control (dip in water only)	

A randomised complete block design with four replicates was used and each replicate consisted of one hand of unbruised, healthy banana with 12 to 18 fruits. The fruit samples were subjected to the above treatments and then air dried prior to artificial ripening with ethylene gas under temperature controlled conditions (16 - 18°C) for 4 days.

After the ripening treatment, the fruits were removed and allowed to ripen at ambient laboratory conditions and were assessed for crown rot (on the 5th, 7th and 9th days after harvest) until the fruits attained optimal ripeness(colour score 6). The severity of infection was measured in terms of a disease index based on a slightly modified scale of (0 - 5) developed by Frossard and Laville, 1973,

where

0= Apparently healthy fruits
1= slight infection
2= 25 % of crown infected
3= 50 % of crown infected
4= 100 % of crown infected
5= Entire crown infected and infection progressing towards the pedicels

Extension of shelf life of fruits after industrially ripening

A trial was conducted to determine the best storage condition for marketing ripened bananas as to extend its shelf life and maintain the post-harvest quality. Banana c.v. Dwarf Cavendish was harvested at full ¾angularity (finger diameter 32 – 33 mm), bunches dehanded and from each bunch 4 clusters of 6 fruits of the second and third hands were selected. The fruits were industrially ripened for a period of 4 days and after which they were removed and scored for peel colour and then stored at different storage conditions namely:

cool (18°C),
ambient (mean 22.5°C) and
simulated warm market conditions (26 °C)

The fruits were assessed daily for weight loss, peel colour and shelf life.

RESULTS AND DISCUSSION

Determination of a harvest maturity index

Results for determination of a harvest maturity index are shown in Tables 1, 2 and 3.

Table 1 Maturity indices of banana variety Williams of different harvest ages grown at Britannia S. E. (1997)

Harvest age	Mean finger						Pulp / peel Ratio	
	Weight		Length		Diameter			
weeks	*g*	S.E ±	*cm*	S.E ±	*mm*	S.E ±	Ratio	S.E ±
12	110.41	1.96	19.50a	0.45	30.70a	0.03	0.97a	0.01
13	116.83	2.01	19.59a	0.17	31.14a	0.05	0.99a	0.01
14	123.79	2.62	19.75b	0.27	32.32b	0.04	1.15b	0.03
15	124.31	3.86	20.17c	0.24	32.53b	0.44	1.24c	0.02

At Britannia Sugar Estates correlation coefficient between harvest age and other parameters varied between 0.867 and 0.964 and the highest correlation was observed between mean finger diameter and harvest age. Furthermore, regression analysis showed a high regression coefficient (0.928) between pulp / peel ratio and mean finger diameter (0.928), suggestive that finger diameter (caliper grade) can be used as a good index of harvest maturity. Measurement of finger diameter on a pre-determined finger on each bunch is relatively easy to be carried out in the field and is a non-destructive method of determining maturity of bananas. It gives a good indication of the angularity of the fruit (degree of fillness)

The pulp/peel ratio of 1:1 and above (corresponding to finger diameter greater or equal to 32 mm and harvest age greater or equal to 14 weeks for banana c.v, Williams, grown at Britannia) is considered to be a very good indicator of banana harvest maturity (of minimum acceptable level of maturity for

ripening and ensuring an acceptable eating quality of bananas, Dalal et al (1970)). However, being a destructive method of analysis, it is of limited practical commercial application.

The pulp / peel ratio of less than 1:1 recorded on 12 and 13 weeks old bunches showed that these had not attained the harvest maturity to ensure minimum acceptable eating quality.

High variations in mean fruit weight made it an unreliable index, and this can be explained by the fact that all bunches did not have equal number of fingers. From **Table 2**, it is evident that bunches harvested at the same age had a lower mean fruit weight at Wooton S.E as compared to Britannia S.E.

Table 2 Maturity indices of banana variety Williams of different harvest ages at Wooton ES. (1997)

Harvest age	Mean fruit weight	Mean finger length	Mean finger diameter	Pulp / peel
weeks	*g*	*cm*	*mm*	*ratio*
13	93.6	17.50	29.30	0.94
14	92.0	17.50	30.12	0.98
15	97.7	17.75	31.81	1.01
16	103.2	17.72	31.85	1.01
17	112.0	18.21	33.62	1.14
18	116.6	18.29	32.72	1.16
19	125.0	18.85	33.91	1.22

The mean pulp / peel ratio of 15 week old banana bunches harvested at Britannia (1.15) corresponded to that of bunches harvested 17 weeks or later at Wooton. This shows the bunch growth rate varies with the locality. It may be due to differences in climatic conditions and management practices. Thus, harvest age alone cannot be used to assess harvest maturity of a particular banana variety on a wider geographical basis.

Data obtained at Médine on the banana cultivar Dwarf Cavendish revealed that bunches developing in winter had a lower mean fruit weight that those recorded in summer when harvested at the same age. This difference in growth rate may be attributed to variations in sum of mean daily temperatures obtained during the bunch growth cycle as has been reported by Ganry et al, 1978. This seasonal variation implies harvesting of winter developing bunches will require the adoption of a more extended flower emergence to harvest period as compared to those developing in the hot summer months. Hence, the use of bunch age control alone for harvesting of a specific banana variety even in one specific site does not provide adequate guarantee that the fruits will be of uniform maturity.

Previous research (Montoyo et al, 1984) has shown that it is impossible to set finger diameter or bunch age limit alone for universal application since the growth rate varied substantially according to fruit growing conditions. However, both bunch age and finger diameter should be used together as indices of harvest maturity. They can be performed relatively easy by banana growers in the field by use of simple equipment known as a vernier calliper or by tagging the bunch with a coloured ribbon as soon as it emerges. Special banana calliper to assess banana maturity exists in banana exporting countries. Consequently, introduction of this simple equipment among our banana growers can prove useful.

Table 3 Maturity indices of banana variety Dwarf Cavendish at different harvest ages at Médine S. E (1997/1998)

Bearing period		Harvest Age *weeks*	Fruit weight *g*		Finger length *cm*		Finger diameter *mm*		Pulp / peel ratio	
			Mean	S.E ±	Mean	S.E ±	Mean	S.E ±	Mean	S.E ±
Summer	Temperature range 21-30°C	12	99.8	*2.24*	17.4	*0.17*	29.6	*0.02*	0.93	*0.02*
		13	106.6	*5.56*	17.2	*0.51*	29.8	*0.13*	1.04	*0.05*
		14	114.5	*9.02*	17.4	*0.73*	29.5	*0.17*	1.08	*0.04*
		15	108.2	*3.78*	17.4	*0.18*	29.9	*0.07*	1.08	*0.06*
		16	112.3	*4.78*	18.6	*0.40*	31.6	*0.03*	1.10	*0.05*
Winter	Temperature range 19-28°C	13	86.6	*0.89*	17.3	*0.10*	28.0	*0.03*	0.93	*0.02*
		14	88.2	*1.63*	17.5	*0.50*	28.6	*0.06*	0.95	*0.02*
		15	91.4	*2.52*	18.2	*0.12*	29.2	*0.02*	0.97	*0.03*
		16	93.6	*2.69*	19.3	*0.25*	31.4	*0.07*	1.01	*0.01*
		17	91.0	*1.16*	19.1	*0.12*	30.8	*0.08*	1.07	*0.05*
		18	106.9	1.65	19.6	0.10	31.3	0.08	1.21	0.01

Effect of bunch harvest age on the quality and shelf life of banana

From results shown in **Table 4**, 12 week old harvested bunches had a mean shelf life of 8 days as compared to 7 days for bunches of 14, 16 and 18 weeks old. It clearly indicated that 14 to 18 weeks old bunches could be harvested together since they gave a uniform ripening when ripened industrially.

Table 4 Effect of harvest age on the post harvest quality of industrially ripened bananas c.v. Williams at Anna, Médine stored at ambient conditions

Bunch Harvest age *Weeks*	Mean shelf life *days*	Mean brix at c.s 6
12	8	14.53
14	7	15.08
16	7	15.03
18	7	15.15

c.s – colour score

Mean values of the pulp brix measured when the fruit reaches colour score 6 showed that fruits of 14 to 18 weeks old bunches were slightly higher than value recorded on fruits of the 12 weeks old bunches. The fact that sweetness is an important characteristic Determining quality of banana, the mean brix values clearly demonstrate that bunches harvested too early (12 weeks old or less) is of an inferior quality than those harvested a more advanced stage.

Appraisal, identification and control of major post-harvest diseases on banana

Crown rot disease was the major post-harvest disease identified on ripening bananas in Mauritius followed by anthracnose and blossom end rot (**Table 5**).

Crown rot was found to be due to a complex of fungal pathogens, namely *Fusarium* sp., *Colletotrichum* sp., *Verticilium* sp and *Cladosporium* sp. It was found to develop rapidly during fruit ripening thereby reducing the quality and marketability of fruits.

In evaluation of fungicides, all four fungicides provided a good control of the crown rot disease as compared to the control (**Table 6**). In the latter case, crown rot development was evident 5 days after ripening treatment and the infection progressed rapidly as the fruit ripened over time resulting in severe rotting of the crowns 4 days later (ripening index 5 to 6). This resulted in a decrease in the shelf life as well as the marketability of the fruits.

Table 5 Diseases and disorders recorded on ripening banana in market surveys, 1997/1998

Disease / Disorders	Frequency of occurrence	Micro-organisms isolated
Crown rot	86	*Fusarium sp. Collectotrichum sp., Cladosporium sp., Verticillium sp.*
Peel injury ,Bruising and Anthracnose	60	*Colletotrichum sp., Fusarium sp.*
Anthracnose	9	*Colletotrichum sp.*
Anthracnose (latent)	8	*Colletotrichum sp.*
Blossom end rot	8	*Colletotrichum sp., Fusarium sp.*
Ripe rot	5	*Fusarium sp.*
Uneven ripening	3	

Benomyl and thiabendazole were found to be superior as compared to chlorothalonil and prochloraz probably due to their persistence. Eating quality of fruits assessed through an informal taste panel showed that prochloraz treated fruits developed off taste. No phytotoxicity was noted in any of the treatments.

Table 6 : Control of crown rot disease on banana, (1997/1998)

Fungicide	Conc *ppm*	Days after harvest		
		5	7	9
		Mean Crown rot		
Thiabendazole	500	0	0.1	0.3
	1000	0	0	0
Benomyl	250	0	0.1	0.3
	500	0	0	0
Chlorothalonil	500	0.4	1.2	1.3
	1000	0.1	0.2	0.9
Prochloraz	500	0.3	0.3	0.3
	1000	0.3	0.3	0.3
Control (water)		2	3.2	4.1

Thiabendazole (@ 500, 1000 ppm) and benomyl (@ 250, 500 ppm) gave better control of the disease. Moreover, it was noted that the higher dosage gave better control over time compared to the lower dosage where minor symptoms of crown rot development on some hands were recorded 7 and 9 days after treatment.

Extension of shelf life of fruits after industrial ripening

The temperature at which industrially ripened banana fruits is stored has a definite significant effect on its subsequent shelf life. Industrially ripened fruits showed a shelf life from 8 to 7 and only 4 days when stored at 18°C, ambient room temperature (mean 22.5 °C) and simulated warm market conditions (26 °C) respectively (**Table 7**).

Table 7 Mean colour score of industrially ripened fruits stored at different storage temperatures

Days after harvest	0	4	5	6	7	8	9	12	13	Mean % weight loss / fruit when fruit attain eating quality (c.s 6)
Ambient, industrial ripening	1.0	2.0	2.9	3.6	4.3	5.2	6.4	7.0		13.3
18°C, industrial ripening	1.0	2.0	2.4	3.0	4.0	5.0	6.0	6.6	7.0	7.8
26 °C, industrial ripening	1.0	2.0	2.4	3.4*	3.5**					9.1

Presence of Brown Flecks: * mild ** severe

Bananas stored under the simulated warm market conditions (26 °C) fail to completely degreen, resulting in "green-ripe" fruits which are ripe in for every other aspects than peel colour. After 3 days storage at 26°C, the fruits showed a mean peel colour score of 3.42 accompanied with the apparition of brown flecks. The pulp softened rapidly into slimy texture with a strong unpleasant ester smell. This storage condition also favoured the development of fungal infection particularly anthracnose which developed as brown patches on the peel and caused the pedicel disintegration. This is a common problem often reported by banana growers and handlers particularly in the summer. It may be due to overheating as a result of poor ventilation during ripening or storage. In the tropics, it has been reported that bananas of the Cavendish group fail to degreen when ripened at high temperatures (> 24°C)(Blackbourn et al 1990).

CONCLUSION

From studies carried out, finger diameter (caliper grade) in combination with bunch age was found to be a reliable index to determine time of harvest. Pulp / peel ratio alone was found to be a reliable index too but not practical, being a destructive method. Mean fruit weight was found to be a non-reliable parameter due to the fact that bunches did not have equal number of fingers.

Crown rot was the major post-harvest disease identified on ripening bananas. Thiabendazole at the rate of 500 and 1000 ppm and benomyl at the rate of 250 and 500 ppm provided good control of the disease when used as a post harvest dip immediately after harvest. However, with the higher dosages control over a longer period of time was obtained.

Industrially ripened bananas was found to have the longest shelf life when stored at 18 °C for up to 8 days as compared 7 days for ambient conditions and 4 days at simulated warm market condition. The extension in shelf life of ripened banana obtained at 18 °C represents an improvement in the marketability of bananas.

ACKNOWLEDGEMENTS

I wish to express my thanks to : Mr S.P.Beni Madhu, Principal Research Scientist of the Plant Pathology Division of AREU for reviewing the manuscript and Mr R.K.Ramnauth, Biometrician for the statistical advice and guidance

REFERENCES

BLACKBOURN H., JOHN P. 1990 - *The effect of high temperature on degreening in ripening bananas.* Plant Science Laboratories, University of Reading, Whiteknights, Reading RG6 2AS, UK.

DALAL M et al. 1970. Recherche d'une méthode d'estimation de la date de récolte du bananier à partir de données climatiques dans les conditions des Antilles

JOHN P and MARCHAL J. 1995. Ripening and biochemistry of the fruit. *In* Gowen S. ed. 1995. *Bananas and Plaintains.*

LASSOUDIERE A, MAUBERT P. 1971. Évolution des dimensions des bananes entre l'émission de l'inflorescence et la récolte du régime. *Fruits*. Vol, 26, n^0 5, 1971

LEBIBET D, METZIDAKIS I and GERASOPOULOS D. 1995 – Effect of storage temperatures on the ripening response of banana (Musa. Sp.) fruit grown in the mild winter climate of Crete. *Acta Horticulturae* 379, 1995

MONTOYA J, MARRIOT J, QUIMI VH and CAYGILL JC. 1984. Récolte en fonction de l'age des bananes dans les conditions de L'equateur. *Fruits*. Mai 1984, vol.39, no. 5, p. 293 – 296

NICOLAS JS, THOMPSON S, THOMPSON AK. 1986. The effects of temperature, concentration and exposure time of acetylene on initiation of banana ripening. *J. .Sci. Food Agric*. 1987, 40, p43-50

NOLIN J. 1985. Etat de maturité des bananes (Cv. Giant Cavendish) à la récolte: une nouvelle méthode de mesure. *Fruits*. Vol. 40, n^0 10, 1985

THOMPSON AL. 1996. Postharvest Technology of fruits and Vegetables.

STATUS OF THE MARINE ENVIRONMENT OF THE ALBION LAGOON

V Chinea, V Chooramum, M Nallee, Y Basant Rai, M Hurbungs and CN Paupiah

Albion Fisheries Research Centre

ABSTRACT

A study on the ecology of the Albion lagoon was made during 1997-1999 to obtain baseline information on the physico-chemical characteristics of the water, species and extent of coral cover, ichthyofauna, bacterial indicators of pollution and benthic dinoflagellates. While the temperature of the water varied between 22.0 and 31.0 ^{o}C, salinity ranged from 8.0 to 35.4 ppt. Though, the values of dissolved oxygen concentration (DO) and chemical oxygen demand (COD) fluctuated widely, pH values had narrow fluctuation. The concentrations of nitrate-nitrogen and phosphate were <0.1-3.8 and <0.01-0.71 mgl^{-1} respectively. The speed of the current in the lagoon ranged from 0.05 to 0.42ms^{-1} and the course of the current was generally southwesterly irrespective of the tides. Coral reef monitoring indicated the existence of 20 species of corals belonging to 8 genera; of which, Acropora spp. were dominant. The fishes collected from the lagoon belonged to 87 species representing 53 genera under 23 families and 7 orders. The number of total coliform (TC) and faecal coliform (FC) bacteria were within the guideline limits at the public beach. The benthic dinoflagellates associated with macroalgae belonged to the genera, Gambierdiscus, Ostreopsis, Prorocentrum, Amphidinium and Coolia and their number varied between 1 and 25 cells g^{-1} of macroalga.

Keywords : lagoons**,** lagoon ecology, water quality, current, corals, indicator bacteria, dinoflagellates, physico-chemical indicators, Albion, Mauritius

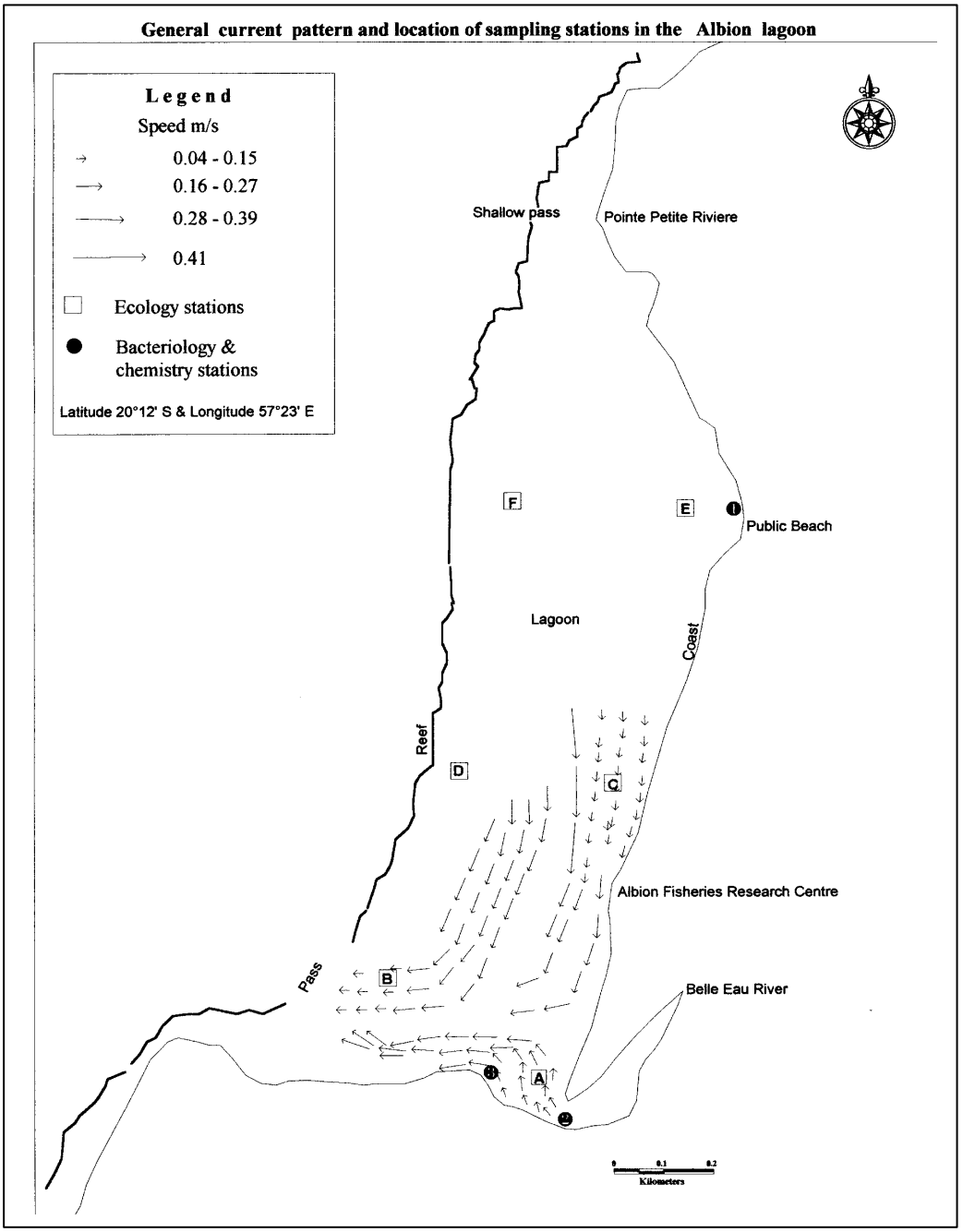
INTRODUCTION

A thorough knowledge on the coastal zone is essential for planning sustainable development of an area. Any damage to the coastal zone will have its resulting impact on the EEZ, the repository of valuable resources. Information available on the seasonal distribution of water quality parameters of the lagoons of Mauritius, especially from the Albion lagoon to understand the dynamics, is scanty (Jehangeer 1978; Munbodh et al. 1988; MFMR 1998). Hence, a comprehensive study was undertaken during 1997–1998 on the physico-chemical characteristics of the water, bacterial indicators of pollution, and benthic dinoflagellates suspected to be associated with ciguatera fish poisoning, and during May and June 1999 on the corals and fish fauna in the Albion lagoon. The results of the study along with the current pattern investigated during 1991-1992 and subsequently during 1999 in the lagoon are reported in the paper.

DESCRIPTION OF THE STUDY AREA

The lagoon at Albion located in the western coast of Mauritius (lat. 20^{o}12' S; lon. 57^{o}23'E) is enclosed by the fringing coral reef and stretches between Pointe aux Caves in the north and Pointe Moyenne in the south (**Figure 1**). The length of the lagoon is about 1.8 km. The reef situated 800m offshore runs inshore, both in the northern and southern ends enclosing an area of about 1.7 km^{2}. While the lagoon is shallow in most of the areas (< 2m), it is deeper in the southern end. The tides are semidiurnal type with an amplitude of 1-1.5m. The lagoon has two passes, a shallower one in the north and a relatively deeper one in the south were studied at 3 stations (station 1: public beach; station 2: mouth of the River Belle Eau; station 3: slipway) located in the Albion lagoon (**Figure 1).**

Figure 1 Albion lagoon



Physico-chemical parameters of the water such as surface temperature, salinity, dissolved oxygen (DO), pH, chemical oxygen demand (COD) and the nutrients, nitrate-nitrogen (NO_3-N) and phosphate (PO_4), Surface water samples were collected monthly between10.00 hours and 12.00 hours irrespective of the tides during September 1997 - December 1998 using clean glass bottles. While the temperature of water was measured to the nearest 0.5°C along with pH *in situ* using a portable TOA-pH meter, water samples were transported to the laboratory in an isotherm box with ice for the analysis of other parameters. All the analyses were carried out on the same day. Salinity of the water was estimated by Horiba-conductivity meter and dissolved oxygen by Winkler's titration method. COD was determined using the alkaline potassium permanganate method (JIS 1995). The concentrations of NO_3-N and PO_4 were quantified using a HACH DR/2000 Spectrophotometer.

Current pattern

The study of the current pattern in the lagoon was carried out using a set of 10 window shade drogues between May 1991 and November 1992 and again from April 1999 to June 1999. The drogues were set on a line perpendicular to the reef at different locations 25-30m apart and the position of each of them was recorded using a Scout Master Global Positioning System (GPS) set up to display coordinates in the Universal Transverse Mercator (UTM) projection system on WGS 84 datum. As the drogue moved with the current, the GPS positions and time were recorded. All the points of a particular drogue were joined together to form a polyline to indicate the movement of the drogue in the lagoon. Likewise, a series of polyline was produced for various segments from the movement of the other drogues. The distance moved by a drogue between two consecutive points was calculated from GPS recordings and the data obtained was used to determine the velocity of the current in metre/second (ms^{-1}).

Coral Ecosystem and fish fauna

Data on species of corals and the percentages of substrate cover for both living and non-living forms were collected during May-June 1999 at a depth of 1.5 –2.0m by diving at 6 stations (stations : A, B, C, D, E and F) in the lagoon (**Figure 1**). At each station, the data recordings were carried out along five 20m line intercept transects laid in parallel to the shoreline following the procedure given by English et al. (1997). The species of corals were identified *in situ*. At the same time, the general substrate condition was observed and the transition points between the different communities were recorded by GPS. Collected data was then extrapolated in order to constitute the zonation map (**Figure 2**).

For estimation of species composition and abundance of fish fauna of the lagoon, a total area of $12000m^2$ representing $2000m^2$ from each of the 6 stations was surveyed during the same period (May-June 1999) by Roving Diver Technique (RDT) (Schmitt and Sullivan 1996)

Coliform indicators

For the estimation of coliform indicators, water samples were collected once a month between 10h and 12h from stations 1, 2 and 3 (**Figure 1**) during January 1997 – December 1998 using sterile 1 litre glass bottles and kept at 4^oC in the refrigerator. The coliform indicators were quantified using the Membrane Filter Method (APHA 1995). All the samples were processed within 6h after collection using a vacuum pump. After incubation of membrane filters on cellulose pads saturated with BBL M-Endo broth (35 ± 0.5°C, 24 h) the number of total coliform (TC) bacteria were estimated. For faecal coliform (FC) bacteria the cellulose pads were saturated with the m-FC broth base, DIFCO (44.5 ± 0.5°C, 24 h). The presence of faecal coliform bacteria was confirmed using the EC-broth (Hi-Media) (44.5 ± 0.5°C, 24 h). The number of colony forming units (CFU) was calculated for 100ml of sample after 24h incubation.

Benthic dinoflagellates

The macroalgae *Jania* sp., *Gracillaria* sp., and *Hypnea* sp. were collected monthly between January 1997 and December 1998 from 2 locations in the lagoon to identify and quantify the benthic dinoflagellates associated with macroalgae (**Figure 1)**. The macroalgae were hand picked and placed in ziplock bags containing seawater and brought to the laboratory.

The plastic bags containing the sample were shaken vigorously to release the dinoflagellates associated with the macroalgae. The mixture was passed consecutively over 150 µm and 38 µm sieves. The macroalgae were dried using absorbent paper and their weights were noted. The residue on the 38 µm sieve was collected using with a jet of seawater into a beaker and the volume was brought to 50 ml. The beaker was gently shaken and 1ml of the mixture was placed onto a Sedgewick Rafter counting cell to estimate the number of cells. The result was expressed as number of cells number of cells per gram of macroalga. In 1997, no quantitative estimation was effected. The benthic dinoflagellates were identified up to generic/species level (Taylor et al. 1995).

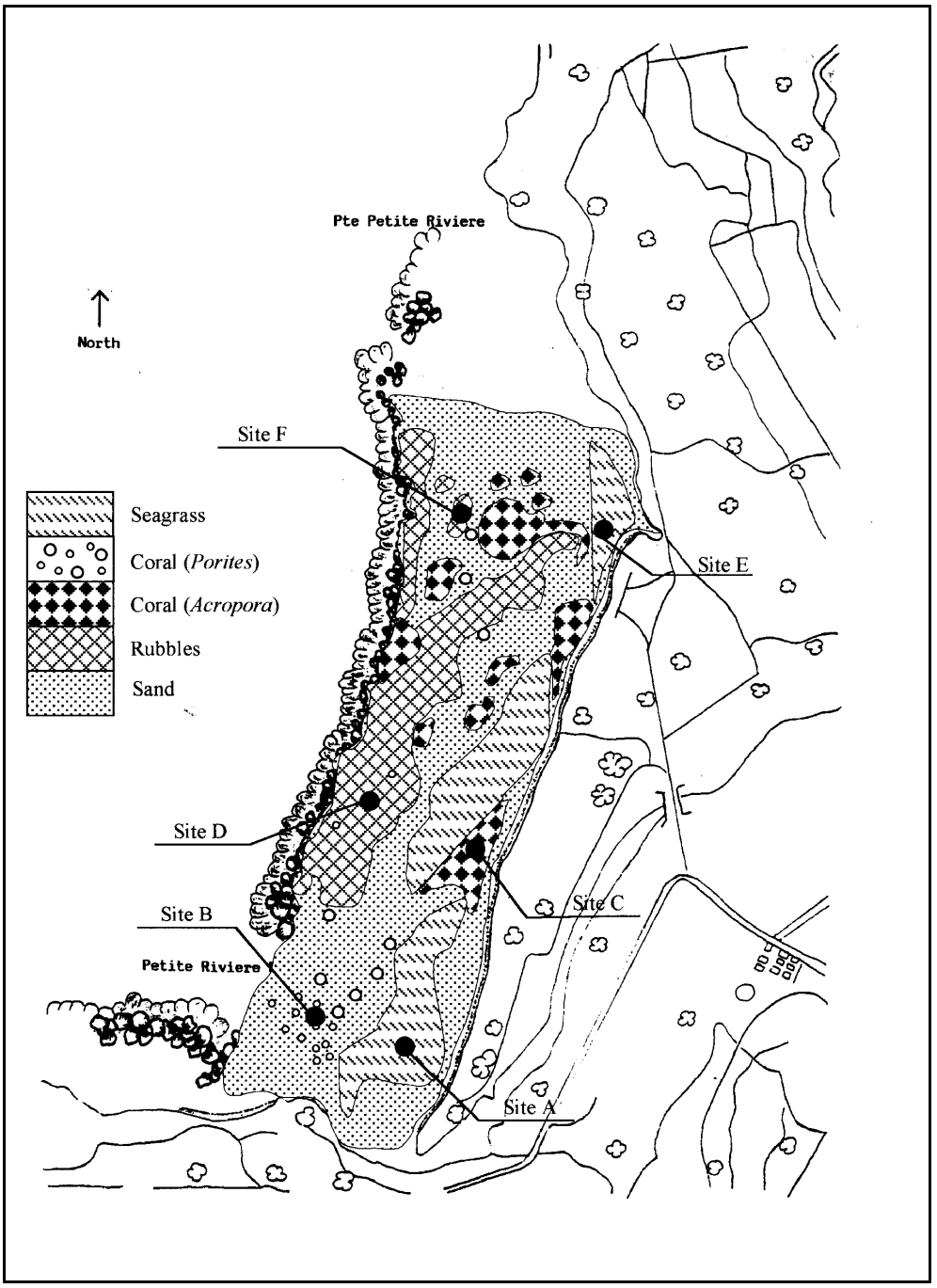
RESULTS

Physico-chemical parameters

Temperature

Monthly variations of the surface water temperature during the period of study are provided in **Figure 3.** The values ranged from 22.5 to 31.0°C in station 1, from 22.0 to 31.0°C in station 2 and from 23.0 to 30.0°C in station 3. The lowest value was recorded in station 2.

Figure 2 Salinity variations of water during different months at various stations



Salinity

Figure. 3 shows the salinity variations of water during different months at various stations. The minimum and maximum values recorded in station 1 were 31.3 and 35.4 ppt, in station 2 were 8.0 and 33.9 ppt, and in station 3 were 9.9 and 32.6 ppt. The lower salinity recorded in stations 2 and 3 might be due to the fresh water inflow from the land and river runoff that diluted the lagoon water.

Dissolved oxygen

The DO values varied between 4.7 mg l^{-1} and 10.3 mg l^{-1} at station 1, between 4.0 mg l^{-1} and 9.5 mg l^{-1} at station 2 and 4.0 mg l^{-1} and 9.6 mg l^{-1} at station 3 (**Figure 3**). The lower DO values were recorded in all the stations during January 1998

pH

The highest pH value (8.5) was recorded in station 1 both during January and February 1998 and the lowest value (6.8) in station 2 during July 1998. The seasonal variation in the values of pH in all the 3 stations is shown in **Figure 3**. Station 1 had consistency in the distribution of pH throughout the year excepting during July 1998 unlike in stations 2 and 3 where fluctuations were comparatively higher.

Chemical oxygen demand

The variations in the COD values during different months in the Albion lagoon are shown in **Figure 3**. The values during the period of study ranged between <0.1 mg l^{-1} and 1.0 mg l^{-1}, <0.1 mg l^{-1} and 2.3 mg l^{-1}, and <0.1 mg l^{-1} and 1.5 mg l^{-1} in the stations 1, 2 and 3 respectively.

Nitrate-nitrogen (NO_3-N)

The nitrate-nitrogen concentration was always <0.1mg l^{-1} in station 1. While in station 2, the values ranged from <0.1 mg l^{-1} to 3.2 mg l^{-1}; in station 3, the values recorded were between <0.1mg l^{-1} and 3.8 mg l^{-1} (**Figure 3**).

Phosphate (PO_4)

Figure 3 shows the seasonal trend of phosphate concentrations in various stations during 1997-1998. Among the stations, the maximum phosphate level was noted in station-2 located at the Belle Eau river mouth indicating input from land sources. While the phosphate value ranged from <0.01 mg l^{-1} to 0.09 mgl^{-1} in station-1, stations 2 and 3 had the ranges from 0.01 mg l^{-1} to 0.71 mg l^{-1} and from 0.04 mg l^{-1} to 0.35 mg l^{-1} respectively.

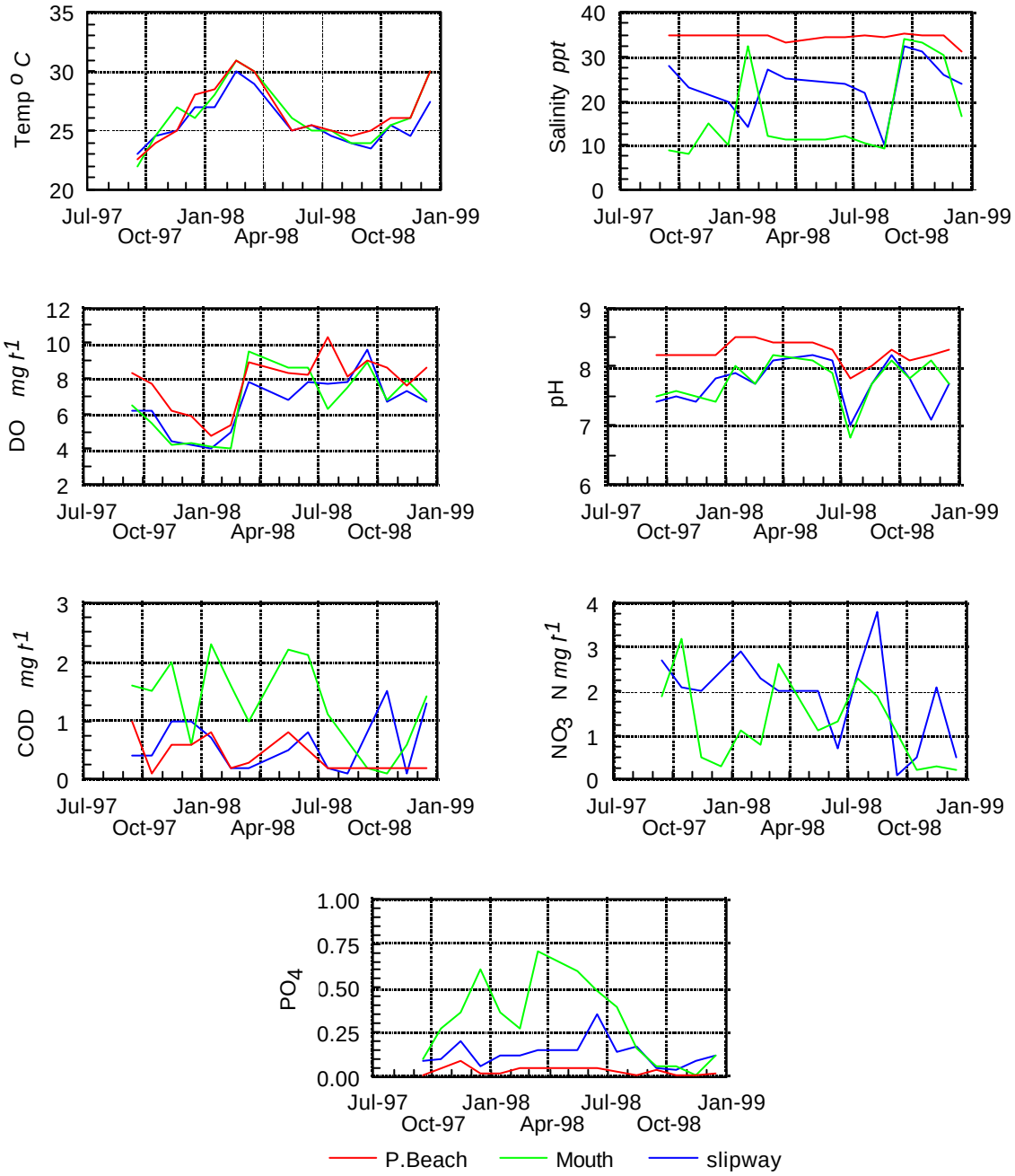
Current pattern

The subsurface current within the 1m water depth showed the speed to range from 0.05ms $^{-1}$ to 0.42ms $^{-1}$ during flood tide and from 0.10 ms $^{-1}$ to 0.23 ms $^{-1}$ during ebb tide. **Table 1** shows the speed and direction of the current during different tides on the days of the drogue study. The current showed a general flow from north to southwest (**Figure 1**).

Coral ecosystem and fish fauna

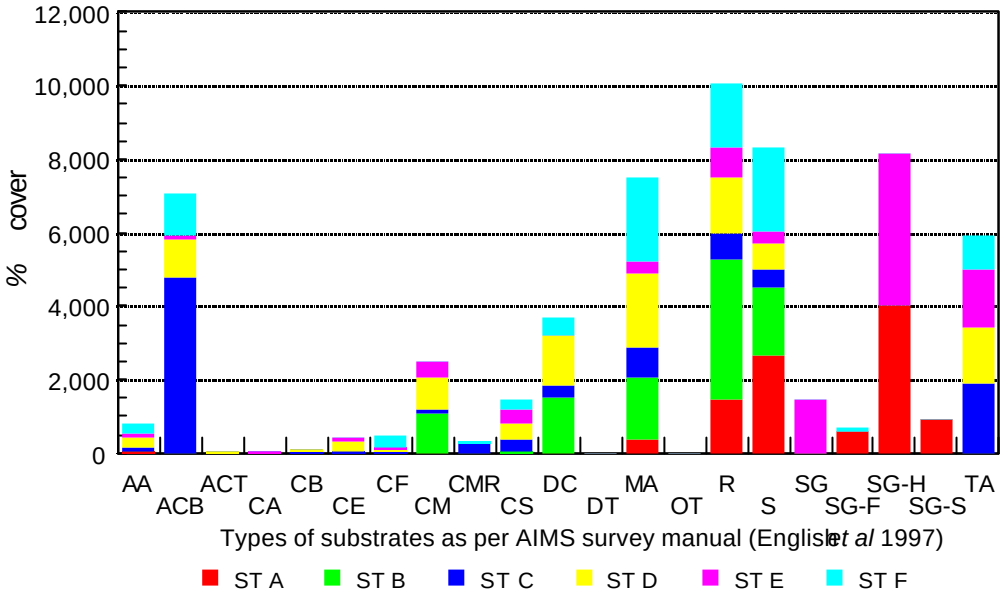
Altogether 20 species of corals belonging to 8 genera have been observed in the lagoon. They are as follows: *Acropora austera*, *A. nasuta*, *A. lutkeni*, *A. latistella*, *A. hyacinthus*, *A. robusta*, *A. cytherea*, *A. tenuis*, *A. formosa*, *A. danai*, *A. nobilis*, *Porites lutea*, *Porites* sp., *Pocillopora damicornis*, *Pocillopora* sp., *Montipora* spp., *Fungia valida*, *Lobophyllia* sp., *Goniopora* sp., *Millepora* sp. The zonation map of substrate distribution in the Albion lagoon is shown at **Figure 2**. The percentages of substrate cover by the living and non-living forms in all the six stations are shown in **Figure 4**.

Figure 3 Physico chemical parameters



At station A, the seagrass *Halodule uninervis*, represented the maximum cover (40%). At station B, which was close to the pass, although rubble contributed to 39% of the substrate, massive Porites were evenly scattered (11%). At station C, *Acropora* sp was dominant (48%). At station D, macroalgae and turf algae together constituted 35% of the substrate cover. At station E, the dominant biota was seagrass (43%) while at station F, the main feature was sandy bottom (23%) with regular patches of macroalgae (23%), branching corals (12%).

Figure 4 Subtrate cover at Albion Lagoon



Abbreviations					
AA	Algal assemblage	CM	Coral massive	R	Rubble
ACB	Acropora branching	CMR	Coral mushroom	S	Sand
ACT	Acropora tabulate	CS	Submassive coral	SG	Combined patches of SG-S,H & F
CA	Coraline algae	DC	Dead coral	SG-H	Seagrass *Halodule*
CB	Coral branching	DT	Dead coral tabulate	SG-F	Seagrass *Halophila*
CE	Coral encrusting	MA	Macroalgae	SG-S	Seagrass *Syringodium*
CF	Coral foliose	OT	Others	TA	Turf Algae

The species composition of fish occurring in the lagoon is given in **Annex 1**. 87 species of fishes belonging to 53 genera and 23 families under 7 orders indicate the richness in fish faunal diversity.

Coliform indicators

Tables 3 and 4 show the load of TC and FC bacteria in the waters of Albion lagoon. In station 1, while the TC counts varied from 10 to 100 CFU/100ml during 1997, a wider range in their distribution (<1-235 CFU/100ml) was observed in 1998. The values of FC also had a similar trend during both years. In general, a higher load of indicator bacteria was discernible during 1998.

The estimated TC and FC colony forming units per 100 ml showed the highest levels in station 2 with an average of 1459 and 458 during 1997 and 1073 and 351 during 1998 respectively. During 1997, the maximum value of TC was recorded in June (3,233) and the minimum was recorded in November (600). The densities of TC and FC were comparatively lesser during 1998 with a minimum of 85 and 17 respectively in August, and a maximum of 2535 and 1570 respectively in May.

Table 3 Variation of TC and FC level at different stations in the Albion Lagon - Year 1997

Month	Station 1		Station 2		Station 3	
	TC	FC	TC	FC	TC	FC
January	51	48	2900	1400	610	75
February	10	7	1017	437	390	30
June	33	33	3233	433	116	73
August	100	20	1133	82	218	20
September	40	32	333	167	57	45
October	87	33	NS	NS	13	10
November	48	40	600	290	163	96
December	100	5	1000	400	200	40
Average	59	27	1459	458	221	49

NS: Not Sampled

Table 4 Variation of TC and FC level at different stations in the Albion Lagon - Year 1998

Month	Station 1		Station 2		Station 3	
	TC	FC	TC	FC	TC	FC
January	40	37	600	400	100	37
February	75	50	725	300	368	145
March	125	75	625	250	275	30
May	51	42	2535	1570	808	189
June	< 1	< 1	1750	100	100	30
August	< 1	< 1	85	17	40	8
September	100	27	2000	470	100	32
October	235	70	1235	170	200	< 1
November	200	167	170	100	170	100
December	100	50	1000	135	170	70
Average	81	52	1073	351	233	64

In station 3, during 1997, the minimum and maximum TC values (CFU/100ml) in the water were 13 in October and 610 in January. The minimum and maximum FC values (CFU/100ml) were 10 in October and 96 in November. However, during 1998, the TC load varied from 40 in August to 808 in May and the FC population ranged from <1 in October to 189 in May respectively.

Benthic dinoflagellates

The monthly distribution of the benthic dinoflagellates during 1997 and 1998 in the Albion lagoon are provided in **Tables 5 and 6** respectively. Five species of dinoflagellates namely *Gambierdiscus toxicus, Ostreopsis* sp., *Prorocentrum* sp., *Amphidinium* sp. and *Coolia* sp. were recorded. During, January and February 1998, no dinoflagellate was recorded in the lagoon.

Table 5 Species of benthic dinoflagellates recorded in the Albion lagoon during 1997.

Species/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Gambierdiscus toxicus	nd	nd	P	P	nd	nd	nd	nd	nd	nd	P	nd
Ostreopsis sp.	nd	nd	P	P	P	nd	nd	P	nd	Nd	P	nd
Prorocentrum sp.	nd	P	P	P	P	nd	nd	P	nd	nd	P	nd
Amphidinium sp.	P	nd	P	P	P	nd	nd	P	nd	P	P	nd

nd : not detected; P : Present

Table 6 Density of benthic dinoflagellates associated with macroalgae (number g^{-1} of macroalga) in the Albion lagoon during 1998.

Species/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Gambierdiscus toxicus	nd	nd	5	nd	1	nd	nd	nd	3	15	nd	3
Ostreopsis sp.	nd	nd	3	15	13	1	2	nd	4	5	2	3
Prorocentrum sp.	nd	nd	3	12	nd	nd	2	2	nd	nd	nd	nd
Amphidinium sp.	nd	nd	10	6	2	nd	nd	nd	nd	3	nd	nd
Coolia sp.	nd	nd	4	6	nd	1	25	4	nd	5	1	5

DISCUSSION

The present study provides the information on the physico-chemical and biological status of the Albion lagoon.

Water quality

The distribution pattern of temperature showed higher values during summer months with the peak in February 1998 and lower values during September 1997 in all the stations. In general, the temperature distribution showed a single prominent peak during summer months in the lagoon (**Figure 3**).

The salinity data (**Figure 3**) show that the water in the public beach is least subjected to fluctuations. Though the salinity values fluctuated considerably in the river mouth and near the slipway, the two distinct peaks of values observed during 1998 are indicative of bimodal oscillation of salinity in the lagoon near these stations. The rain and freshwater from the River Belle Eau and agricultural activities would be the probable causes for such variations. Though the pH of the water showed irregular trend (**Figure 3**), station- 1 always had higher pH values than the stations influenced by land drainage. The higher COD values in the river mouth than in the other 2 stations might be due to the high organic content carried by the river water to the lagoon.

The dissolved oxygen concentrations showed 3 peaks during 1998 in all the stations. Though dissolved oxygen concentration has an inverse relationship with salinity in Vellar estuary (Vijayalakshimi and Venugopalan 1973; Thangaraj et al. 1979), no such trend could be seen in the present study. The dissolved oxygen level was lower at the stations during the summer months. The low levels of oxygen recorded can be attributed to the increase in water temperature during the summer season.

In the tropical environment, freshwater discharge forms the major source of nutrient supply to the nearshore waters (Chandran and Ramamoorthi 1984). The nature and extent of freshwater discharge is chiefly controlled by the regime of precipitation during the rainy season and to some extent by the runoff from the irrigation channels. The normal values of nitrate-nitrogen and phosphate in certain lagoons of Mauritius range from 0.1 to 0.2 mg l^{-1} and from 0.02 to 0.04 mg l^{-1} respectively (MCFMRD, 1996). The higher concentrations of nitrate-nitrogen and phosphate observed in the present study in the

south of the lagoon (stations 2 and 3) during most of the months might be due to the discharge from the nearby animal breeding sheds and agricultural activities, besides the rain. Generally the variations in phosphate concentration could be attributed to their utilisation by phytoplankton (Krishnamurthy 1970; Santhakumari 1970) and cessation of freshwater flow. The variations may also be caused by various processes like adsorption and desorption of phosphate and buffering action of sediment under varying environmental conditions (Pomeroy et al. 1965). Further studies on the productivity of the water would throw more light on the seasonal variations of the nutrients in the Albion lagoon.

Current pattern

The current showed a general north - southwesterly flow pattern towards the main pass irrespective of changes in tides. It was noted that during most of the time, the speed of the wind varied from 10 to 20 kmh^{-1}. In June, the prevailing wind showed a south-easterly direction whereas during the summer and transition months wind from the west was recorded on some days (wind recording - Meteorological Services 1991, 1992, 1999). The wind appeared not to influence the current pattern and, in general, the water got into the lagoon over the reef top and drained out through passes.

Coral ecosystem and fish fauna

Among the 11 species of acroporiids recorded in the lagoon, *Acropora. nobilis*, *A. robusta* and *A. cytherea* were dominant. The other genera were represented by a few species each. Mass spawning of the acroporiids viz. *Acropora formosa*, *A. nobilis*, *A. robusta* and *A. cytherea*, which was observed in the lagoon at a depth of 1.0-1.5 m on 3rd november 1998 between 21h and 22h during the full-moon at spring tide, indicates that the environment is healthy for the proliferation and establishment of corals. The results of the substrate cover estimation clearly indicate the site preference by living organisms. The dominance of seagrass in station A where the fluctuation in salinity was very wide due to Belle Eau River discharge and in station E where the salinity fluctuated narrowly shows that the seagrass is not affected by fresh water input and forms an integral part of the biota in the whole of the lagoon. The near total absence of the corals in station A is natural since they are stenohaline. The dominant cover of Acropora in Station C is indicative of a favourable zone for corals in the lagoon.

Fishes belonging to the order Perciformes appear to be dominant in the lagoon. Of the 3865 fish observed, the perches contributed to 97.4%. During the present study, fishes of the family Pomacentridae were found to have wider distribution, The species *Stegastes lividus*, which were especially distributed in Station C (branching coral area), ranked first in abundance with 657 individuals followed by *Dascyllus aruanus* (532 individuals), *Chromis viridis* (358 individuals), and *Abudefduf sparoides* (195 individuals). The other significantly distributed families of fish recorded were Scaridae, Labridae, Mullidae and Acanthuridae. While Tetraodontiformes were represented by 2 families, namely, Tetraodontidae and Balistidae, the other orders, Siluriformes, Beryciformes and Scorpaeniformes, were represented by one family each. The occurrence of 87 species of fishes in an area of about 12000 m^2 indicates the species richness of the Albion lagoon

Coliform indicators

Presence of FC in the water of a locality indicates the existence of other disease causing pathogenic bacteria (Elliot and Colwell 1985). In the present study, the density of both TC and FC bacterial populations was observed in the following order: station 2 > station 3 > station 1. However, no consistency in the seasonal variation of bacterial population was noticed during both years. In station 2, where the fresh water influence is substantial, the higher bacterial count denotes the land source faecal contamination drained mainly from animal rearing sheds located in the region (Basant Rai et al. in press). Besides, the lower saline water that existed through most part of the year in station 2 would have triggered the build up of the bacterial density as high saline water increases the die-off rates of the coliforms (EPA, 1993; NCDEHNR, 1994).

An FC count of more than 200 CFU/100ml indicates a higher risk of infection in case of direct contact with water. Since, the values of indicator bacteria in Station 1 show that their load is below the limit of Guidelines for Coastal Water Quality, 1999 (200CFU/100ml) , the public beach at Albion is safe for recreational and other water sports. This conclusion has also support from the current pattern in the

lagoon that flows from north to southwest. Hence, the faecal contaminated water draining into the lagoon through the Belle Eau River does not reach the public beach in the north. Though in station 3 the FC values do not exceed the limits specified for in the guidelines during most part of the year, higher values during November 1997 and May 1998 are indicative of faecal contamination

Dinoflagellates

Fish toxicity especially ciguatera toxins produced by certain benthic dinoflagellates influences the economic and nutritional aspects of tropical coral island nations (Glaziou and Legrand 1994). The ciguatoxins arise from less oxidised precursors called gambiertoxins which are produced by the benthic dinoflagellate, Gambierdiscus toxicus (Lewis and Holmes 1993; Holmes et al. 1994). The present study shows that the population density of G. toxicus in the Albion lagoon varies from 0-15 cells g^{-1} of macroalga (**Table -6**).

The distribution pattern of G. toxicus in the ciguatera endemic areas varies considerably (Yasumoto et al. 1984). While in French Polynesia, the population of G. toxicus varied from 0 to 54,000 cells g^{-1} of macroalga, the values ranged from 0 to 780 in New Caledonia; however, Guam and Okinawa had 9.8 and 0.05 cells of G. toxicus g^{-1} of macroalga respectively. A comparison of the density of G. toxicus in the Albion lagoon in the present study with other ciguatera endemic regions in the Pacific (Yasumoto et al. 1984) may indicate that Mauritius is a 'moderately toxic area'. However, this has to be confirmed by more studies on the toxicity of the strain of G. toxicus distributed in the Mauritian waters as differences in toxicity levels of G. toxicus between the clones isolated from various geographical regions have been reported (Bomber et al. 1989). Further, in the Caribbean, *G. toxicus* from lower latitudes had higher toxicity indicating that latitudes may have an influence on their toxicity level (Bomber et al. 1989) besides the genetic origin (Durant-Clement 1986).
In the Western Indian Ocean region, ciguatera is associated with the massive proliferation of dinoflagellates like *G. toxicus* and *P. lima* triggered mainly by natural disturbances on the offshore banks and the transmission of phycotoxins to the coral reef food chain (Quod et al. 1995). In the Albion lagoon, the dinoflagellates such as *G. toxicus* , *Ostreopsis* sp, *Prorocentrum* sp, *Amphidinium* sp. and *Coolia* sp. are occurring. Hence, the environmental aspects of fish toxicity should not be overlooked as various human activities and natural disturbances in the coral reef ecosystem can lead to blooming of dinoflagellates.

CONCLUSION

The following conclusions can be drawn from the present study carried out in the Albion lagoon:

The seasonal distribution of temperature shows a prominent peak during summer months.

Variations of salinity of water in most part of the lagoon follow a bimodal oscillation and are influenced by the discharge from Belle Eau River and rain.

The nutrient levels of the water are mainly governed by the land-based activities.

The current flow in the lagoon is always from the north to south-west.

Among the corals, acroporiids establish good substrate cover in the lagoon where salinity fluctuations are negligible.

The lagoon supports a rich fish species diversity mostly belonging to the order perciformes.

The sanitary quality of the water in the public beach at Albion indicates that the beach is safe for recreational purposes.
Occurrence and density of the dinoflagellate Gambierdiscus toxicus indicate that the island may be a 'moderately ciguateric area'. However, this conclusion needs further validation.

REFERENCES

APHA. 1995. *Standard methods for the examination of water and wastewater*. 19th edition, American Public Health Association, Washington, D.C.

BASANT RAI Y, CHINEAH V and NEERMUL P. 1998. Investigation of water quality of Belle Eau estuary at Albion. *In*:*Proceedings of the Annual Meeting of Agricultural Scientists*, Réduit, Food and Agricultural Research Council, Mauritius. (in press)

BOMBER JW, TINDALL DR and MILLER DM. 1989. Genetic variability in toxic potencies among seventeen clones of Gambierdiscus toxicus (Dinophyceae*) Journal of Phycology*. 25:617-635.

CHANDRAN R and RAMAMOORTHI K. 1984. Hydrobiologial studies in the gradient zone of the Vellar estuary : II Nutrients. Mahasagar-*Bulletin of the National Institute of Oceanography*, 17:133-140.

DURANT-CLEMENT M. 1986. A study of toxin production by Gambierdiscus toxicus in culture. *Toxicon*, 24:1153-1157.

ELLIOT EL and COLWELL RR 1985. Indicator organisms for estuarine and marine waters, FEMS *Microbiology Reviews*, Vol. 32, pp. 61-79.

ENGLISH S, WILKINSON C and BAKER V. 1997. *Survey manual for tropical marine resources*. 2nd edition. Australian Institute of Marine Science, Townsville.pp 390.

EPA *see under* Environmental Protection Agency.

ENVIRONMENTAL PROTECTION AGENCY. 1993. *Guidance specifying management measures for sources of nonpoint pollution in coaster waters*. Office of water, Washington, DC. 840-B-92-002. January 1993.

GLAZIOU P and LEGRAND AM. 1994. Review article – The epidemiology of ciguatera fish poisoning. *Toxicon* 32:863-873.

GOVERNMENT OF MAURITIUS. 1999. *Guidelines for Coastal Water Quality* 1999. *General Notice* No. 620 of 1999 on 30 April 1999, Government of Mauritius.

HOLMES MJ, LEWIS RJ, SELLIN M and STREET R. 1994. The origin of ciguatera in Platypus Bay. *Memoirs of Queensland Museum*, 34:497-504.

JEHANGEER MI. 1978. The state of aquatic pollution in Mauritius. In Sixth FAO/SIDA *Workshop on aquatic pollution in relation to protection of living resources* : Scientific and administrative basis for management measures. Nairobi and Mombassa, Kenya, 12 June- 22 July 1978.

JIS. 1995. *Environmental Technology*, Japanese Standards Association, Tokyo, Japan, pp. 2437.

KRISHNAMURTHY K. 1970. *On the ratio of nutrients in the inshore estuarine waters of Porto Novo*. The Ocean World Joint Oceanography Assembly, Tokyo. P.13-25.

LEWIS RJ and HOLMES MJ. 1993. Origin and transfer of toxins involved in ciguatera. *Comparative Biochemistry and Physiology* 106C:615-628.

MCFMRD *see under* Ministry of Cooperatives, Fisheries and Marine Resources Development.

MINISTRY OF COOPERATIVES, FISHERIES AND MARINE RESOURCES DEVELOPMENT. 1996. *Annual report 1996 – Fisheries*. Government of Mauritius. pp. 68.

MFMR *see under* Ministry of Fisheries and marine Resources

MINISTRY OF FISHERIES AND MARINE RESOURCES. 1998. *Status of coral reefs and physico-chemical characteristics of nearshore waters of Mauritius : A baseline study*. Government of Mauritius. p. 108.

MUNBODH M, RAMYEAD T S and KALLEE P. 1988. L'importance economique des recifs coralliens et tentatives d'aquaculture à Maurice. *The Journal of Nature*. 1:56-68.

POMEROY CR, SMITH EE and GRANT CM. 1965. The exchange of phosphate between estuarine water and sediments. *Limnology and Oceanography* 10:167-172.

QUOD JP, TURQUET J, DIOGENE G and FESSARD V. 1995. Screening of extracts of dinoflagellates from coral reefs (Reunion Island, SW Indian Ocean) and their biological activities. P 815-820. In Lassus P, Arzul E, Erard E, Gentien P and Marcaillou C. eds.*Harmful marine algal blooms*, Technique et Documentation, Lavoisier, Intercept Ltd, 1995.

SANTHAKUMARI P. 1970. Seasonal variation in the N:P ratios in the surface water of the mouth of the Vellar estuary. *Journal of Annamalai University*. 28:13-18.

TAYLOR FJR, FUKUYO Y and LARSEN J. 1995. Taxonomy of harmful dinoflagellates. In Hallegraeff G M, Anderson D M and Cembella A D. eds. *Manual on harmful marine microalgae*, IOC Manual and guides No.33, UNESCO 1995.

THANGARAJ GS, SIVAKUMAR V, CHANDRAN R, SANTAHANAM R, SRIKRISHNADHAS B and RAMAMOORTHI K. 1979. An environmental inventory of Porto Novo coastal zone. *Proceedings of the Symposium on Environmental Biology*. 75-87. Academy of Environmental Biology, India.

VIJAYALAKSHIMI GS and VENUGOPALAN VK. 1973. Diurnal variation in the physico-chemical and biological properties in Vellar estuary. *Indian Journal of Marine Sciences*, 1:125-127.

YASUMOTO T, RAJ U and BAGNIS R. 1984. *Seafood poisonings in tropical regions.* Laboratory of Food Hygiene, Tohoku University. P.74.

Annex 1 Species composition of fish in Albion Lagoon

No.	Family name	Genus name	Species small name	No of observed fish at each site (2 000 m^2) total 12 000 m^2						
				A	B	C	D	E	F	Total
1	Muraenidae	*Siderea*	*Grisea*					2		2
2	Plotosidae	*Plotosus*	*lineatus*	20	22					42
3	Belonidae	*Tylosurus*	*crocodilus*					1		1
4	Holocentridae	*Myripristis*	*Berndti*	6	4					10
5	Holocentridae	*Sargocentron*	*diadema*						1	1
6	Scorpaenidae	*Dendrochirus*	*Zebra*	2						2
7	Scorpaenidae	*Pterois*	*volitans*		3					3
8	Scorpaenidae	*Scorpaenopsis*	*diabolus*				1			1
9	Scorpaenidae	*Taenianotus*	*triacanthus*						1	1
10	Serranidae	*Epinephelus*	*Merra*		1	1	1		1	4
11	Serranidae	*Epinephelus*	*hexagonatus*		3	6	1	1	2	13
12	Serranidae	*Epinephelus*	*macrospilos*		1		1			2
13	Serranidae	*Epinephelus*	*spilotoceps*		4	6	2	5	1	18
14	Serranidae	*Grammistes*	*sexlineatus*		1					1
15	Apogonidae	*Apogon*	sp. (juv.)		48					48
16	Apogonidae	*Cheilodipterus*	*macrodon*		2	1			1	4
17	Carangidae	*Caranx*	sp.	1				1		2
18	Gerreidae	*Gerres*	*oyena*					2		2
19	Lethrinidae	*Gnathodentex*	*aureolineatus*			1				1
20	Lethrinidae	*Lethrinus*	*harak*	2	4	1		16		23
21	Lethrinidae	*Monotaxis*	*grandoculis*		2					2
22	Mullidae	*Mulloidichthys*	*flavolineatus*	23	38			38	5	104
23	Mullidae	*Parupeneus*	*barberinus*					1		1
24	Mullidae	*Parupeneus*	*bifasciatus*		18		1			19
25	Mullidae	*Parupeneus*	*ciliatus*			3		1	16	20
26	Mullidae	*Parupeneus*	*cyclostomus*		65					65
27	Mullidae	*Parupeneus*	*macronema*	4		2	8	1	8	23
28	Mullidae	*Parupeneus*	*pleurostigma*		19					19
29	Chaetodontidae	*Chaetodon*	*auriga*		13				2	15
30	Chaetodontidae	*Chaetodon*	*blackburni*		1					1
31	Chaetodontidae	*Chaetodon*	*kleini*		2					2
32	Chaetodontidae	*Chaetodon*	*madagaskariensis*		4					4
33	Chaetodontidae	*Chaetodon*	*melannotus*		1					1
34	Chaetodontidae	*Chaetodon*	*trifascialis*		3					3
35	Chaetodontidae	*Chaetodon*	*trifasciatus*		17	1			1	19
36	Chaetodontidae	*Chaetodon*	*vagabundus*	2	24		1		2	29
37	Pomacentridae	*Abudefduf*	*sexfasciatus*			1				1
38	Pomacentridae	*Abudefduf*	*sparoides*		195					195
39	Pomacentridae	*Chromis*	*viridis*	22		336				358

No.	Family name	Genus name	Species small name	No of observed fish at each site (2 000 m^2) total 12 000 m^2						
				A	B	C	D	E	F	Total
40	Pomacentridae	*Chrysiptera*	*annulata*				2			2
41	Pomacentridae	*Chrysiptera*	*unimaculata*		4		42		1	47
42	Pomacentridae	*Dascyllus*	*aruanus*	50		183			299	532
43	Pomacentridae	*Dascyllus*	*trimaculatus*	1	3					4
44	Pomacentridae	*Plectroglyphidodon*	*dickii*		5					5
45	Pomacentridae	*Plectroglyphidodon*	*johnstonianus*		11	2				13
46	Pomacentridae	*Pomacentrus*	*caeruleus*		16					16
47	Pomacentridae	*Stegastes*	*fasciolatus*				7		32	39
48	Pomacentridae	*Stegastes*	*limbatus*			5				5
49	Pomacentridae	*Stegastes*	*lividus*			574			83	657
50	Pomacentridae	*Stegastes*	*nigricans*			5			106	111
51	Pomacentridae	*Stegastes*	*pelicieri*		8					8
52	Pomacentridae	*Stegastes*	*Sexfasciatus*						6	6
53	Pomacentridae	*Stegastes*	sp.		2	4				6
54	Labridae	*Anampses*	*caeruleopunctatus*		9					9
55	Labridae	*Cheilinus*	*trilobatus*		7	3	4		3	17
56	Labridae	*Cheilio*	*inermis*	8	2	1				11
57	Labridae	*Coris*	*aygula*		5					5
	Labridae	*Coris*	*Aygula* (juv.)		10					10
58	Labridae	*Gomphosus*	*caeruleus*			1			2	3
59	Labridae	*Halichoeres*	*hortulanus*		7					7
60	Labridae	*Halichoeres*	*Hortulanus* (juv.)		8					8
60	Labridae	*Halichoeres*	*marginatus*		41		1			42
61	Labridae	*Halichoeres*	*nebulosus*	3			46		3	52
62	Labridae	*Halichoeres*	*scapularis*	10	40	21	17		10	98
	Labridae	*Halichoeres*	*Scapularis* (juv.)	11						11
63	Labridae	*Labroides*	*dimidiatus*		28	2				30
64	Labridae	*Nvaculichthys*	*taeniurus*				1			1
65	Labridae	*Stethojulis*	*bandanensis*	3	8	6	15	18		50
	Labridae	*Stethojulis*	*Bandanensis* (juv.)				77		7	84
66	Labridae	*Thalassoma*	*genvittatum*		19				2	21
67	Labridae	*Thalassoma*	*hardwickii*			10	25		7	42
68	Labridae	*Thalassoma*	sp. (juv.)		42					42
69	Scaridae	*Leptoscarus*	*vaigiensis*	8	69		4	8		89
	Scaridae	*Leptoscarus*	*Vaigiensis* (juv.)	102				64	69	235
70	Scaridae	*Scarus*	*ghobban*			8				8
71	Scaridae	*Scarus*	*sordidus*		123	39	4		16	182
72	Scaridae	*Scarus*	sp.		4					4
73	Blenniidae	*Ecsenius*	sp.		8					8

No.	Family name	Genus name	Species small name	No of observed fish at each site (2 000 m^2) total 12 000 m^2						
				A	B	C	D	E	F	Total
74	Gobiidae	*Istigobius*	*decoratus*	5				13	1	19
75	Gobiidae		sp.	7						7
76	Siganidae	*Siganus*	*sutor*		28				1	29
77	Zanclidae	*Zanclus*	*cornutus*	1	13	5			5	24
78	Acanthuridae	*Acanthurus*	*triostegus*		41	13	12		7	73
79	Acanthuridae	*Ctenochaetus*	*binotatus*	3	88					91
80	Acanthuridae	*Ctenochaetus*	*strianus*		1					1
81	Balistidae	*Rhinecanthus*	*aculeatus*		3	1			9	13
82	Monacanthidae	*Oxymonacanthus*	*longirostris*						2	2
83	Monacanthidae	*Rhinecanthus*	*aculeatus*				2			2
84	Tetraodontidae	*Arothron*	*nigropunctatus*			1				1
85	Tetraodontidae	*Canthigaster*	*bennetti*		3					3
86	Tetraodontidae	*Canthigaster*	*valentini*	3	7					10
87	Tetraodontidae	*Ostracion*	*meleagris*	3	5					8
	Total			300	1163	1243	275	172	712	3865

SOME RESULTS OF THE STUDY ON SEXUAL MATURITY OF *Lethrinus mahsena* FROM SAYA DE MALHA BANK.

S Soondron, A Venkatasami* and *A Sheik Mamode

Albion Fisheries Research Centre

ABSTRACT

Lethrinus. mahsena commonly known as the 'berri' fish is the most important species caught from the waters of Saya de Malha bank and contributes some 90% of the total catch. The findings reported in this paper are based on biological data collected from October 1996 to January 1998. It is found that matured fish are present throughout the year with peaks occurring during the periods of December to January and May to June. The length at first maturity (Lm_{50}) of the fish is 19 cm while the length at first capture (Lc_{50}) is 26.7 cm. This paper also attempts to evolve guidelines for management control based on fishing effort between Lc_{50} and Lm_{50}.

Keywords : *Lethrinus. mahsena,* 'berri' fish, biological data, Saya de Malha, fishing

INTRODUCTION

L. mahsena commonly known as the berri fish is the most important species caught from the waters of Saya de Malha and contributes to some 85% of the total catch. This paper presents some results of a study undertaken from October 1996 to Jan 1998. It deals with the reproduction of the species, particularly the length at maturity, sex ratio, spawning and some growth parameters. The paper attempts to evolve some guidelines for management using the relationship between length at first capture and length at first maturity.

MATERIALS AND METHODS

Arrangements were made with a bank fishing company to bring ungutted specimens caught on Saya de Malha (South) bank during the fishing trips of its vessel for the period October 1996 to January 1998. Each month, about 200 samples were thus collected for analysis. The length composition of males and females of *L. mahsena*, sex ratio, gonad stages and length at first maturity were assessed based on data of biological analyses for the whole period of investigations (2 288 specimens). Using the length frequency data collected at the Port during the period of the study , estimation of growth parameters were attempted using FISAT and LENA softwares. The asymptotic length, L was estimated by the Wetherall plot. The growth coefficient, K was obtained using the ELEFAN, while natural mortality, M was estimated using Pauly's formula. Length converted catch curve analysis was used to determine the total mortality, Z (**Figure 1**).

Description of maturity of females

Stage 1

The sex glands are thin, transparent and thread like. Sex cells cannot be differentiated with the naked eye. The ovaries are colourless and they do not increase considerably in size and weight.

Stage II

The ovaries occupy a considerable part of the abdominal cavity. The egg at this stage becomes pale yellowish in colour.

Stage III

Mature oocytes present in fish ovaries. The diameter of the eggs is quite large. The colour of the eggs changes from yellowish to orange and are easily seen with the naked eye.

Stage IV (spawning)

The gonads are similar to those at the third stage of maturity, but they appear slightly inflamed and have a yellowish-reddish colour. The eggs are granular.

Stage V (spent)

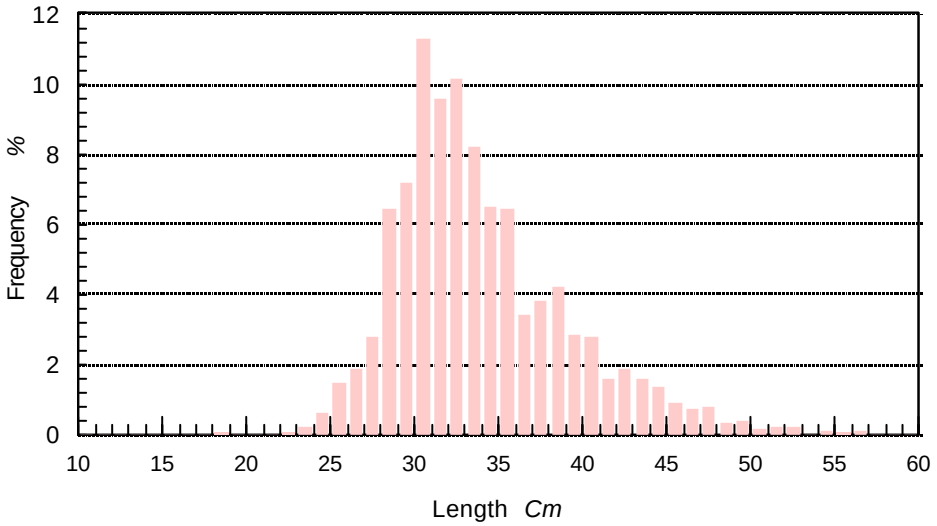
The cavity inside the ovary is red and flabby. This stage characterises the post-spawning state of the ovaries. Accumulation of fat around the sex organs is a regular feature at this stage.

RESULTS

Length composition

The length of fish sampled for analysis varied from 16.5 to 53.7 cm. Length of female varied from 17 to 46.5cm. and that of male from 16.5 to 53.7cm. **Figure 1** shows the length frequency of the samples.

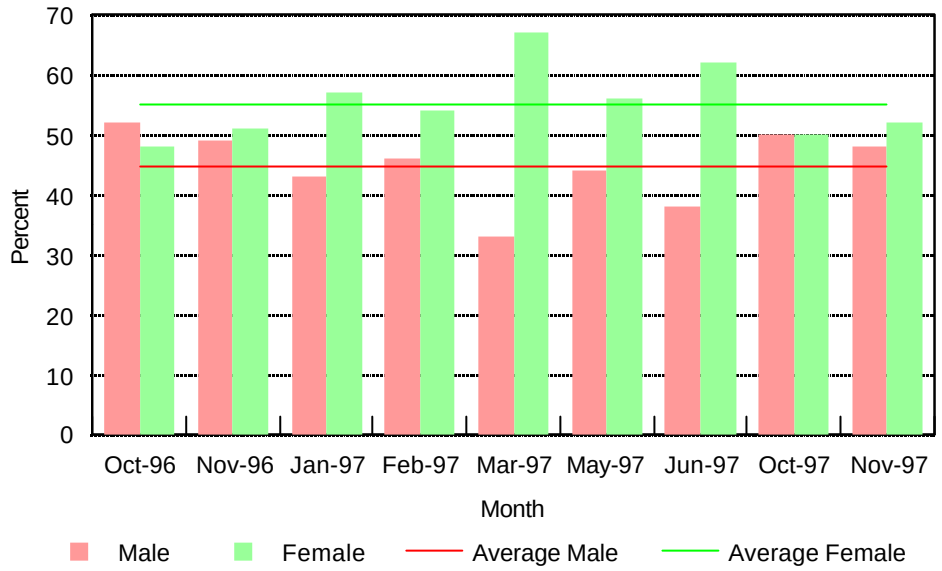
Figure 1 Length frequency distribution



Sex ratio

Sex ratio for the 2 288 fish sampled was approximately 1:1 with some predominance of female during certain periods of the year. **Figure 2** shows the sex ratio by month.

Figure 2 Sex ratio

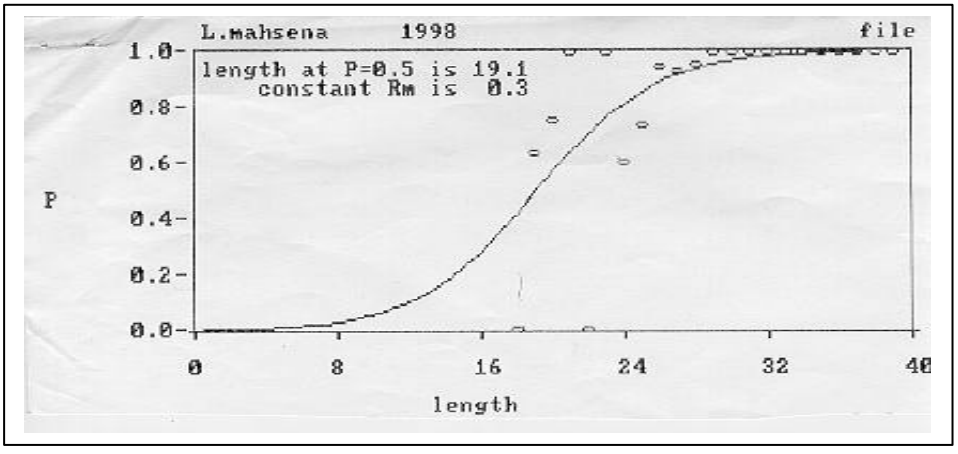


As fish grow and become older, the number of females is reduced. In our analysis, the phenomenon was noted when *L. mahsena* reaches a length of about 40 cm. However sex reversal was not observed as stated by Bertrand (1986).

Length at first maturity (Lm50)

Length at first maturity, (Lm50) i.e length at which 50% of all fish at that length are matured, was found to be 19.1 cm, when the fish is approximately three and a half years old. **Figure 3** showing the selectivity curve of % mature females as a function of size. It is to be noted that the only females at stage II and above were considered matured. However, female *L. mahsena* was observed to spawn for the first time when they are 14 cm long (Ratacharen, pers.comm.)

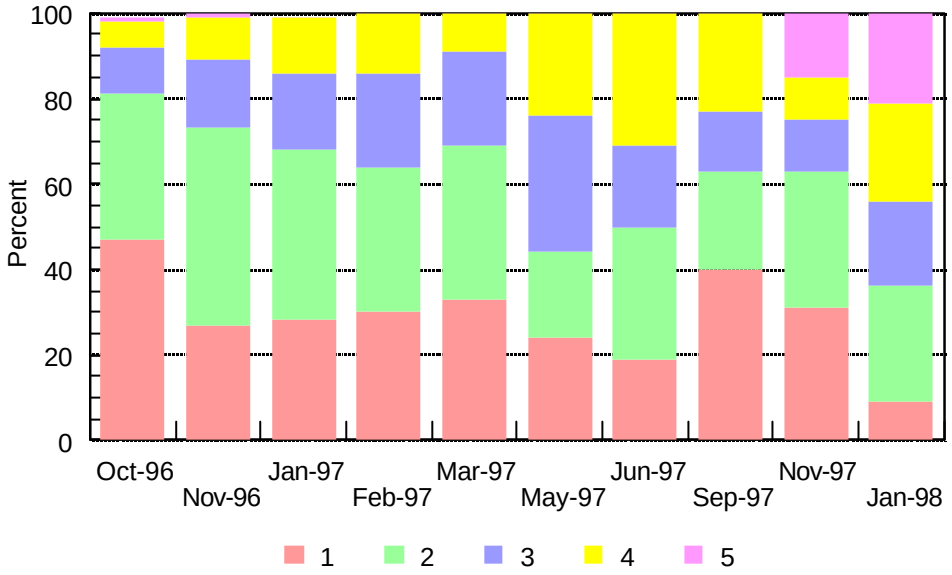
Figure 3 Selectivity curve of percent mature females versus size



Spawning period

An attempt was made to establish the spawning period of *L. mahsena* on Saya de Malha bank based on occurrence of spawning individuals. Mature females and males were found throughout the year but individuals at maturity IV were predominant in December and January and during the period May - June. This indicates that there may be 2 peaks of spawning activity.**Figure 4.**

Figure 4 Maturity stages



Growth parameters

Morphometric data were collected at the fishing port during the period of the study. These data includes species composition and fork length distributions of *L. mahsena*. The length frequency distributions were analysed for length at infinity, L, growth coefficient, K, total mortality, Z and length at first capture, Lc50. **Table 1** shows the parameters estimated from the data collected in 1998.

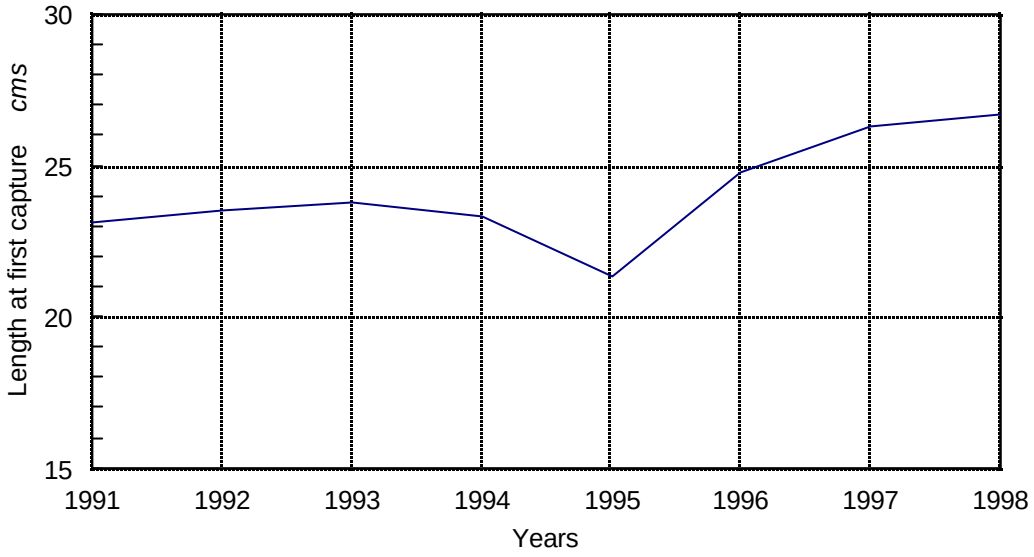
Table 1 Parameters estimated from the data collected in 1998

Bank	L (*cm*)	Z	M	F	K	t_0
Saya de Malha	60.5	0.62	0.3	0.32	0.12	-0.6

Length at first capture (Lc50)

In 1998, the length at first capture of fish caught on Saya de Malha (South) was 26.7cm. **Figure 5** shows the trend in length at first capture of L.mahsena on Saya de Malha bank from 1991 to 1998

Figure 5 Length at first capture on Saya de Malha



CONCLUSION

Two peaks of spawning period occur in May/June and Dec/Jan on the Saya de Malha bank. As the fish grow older the percentage of female individuals is reduced. However, no sex reversal was observed. Length at first maturity is 19.1cm (age=3.5 years). The length at first capture is 26.7cm and is equal to 0.44 L . Lc50 is therefore slightly higher than Lm50. It should, however, be noted that even if Lc50 were equal to Lm50, the small sized fish would face marketing problem and it would not be economically sound to fish at that level. Management of the resource by using Lc50 rather than the mean length would be more appropriate in the shallow water banks fishery. However, care should be taken in the sampling procedure, as very often the catch is segregated according to the size of the fish. Moreover, if fishing is carried out in lightly exploited areas of the banks, bigger size fish would be caught. At the current fishing mortality and length at capture, the fishery is believed to be exploited at sustainable level.

REFERENCES

BERTRAND J. 1986. *Pour une evaluation des resources en capitaine/dame berrie (Lethrinus mashena) des bancs de Saya de Malha*. Rapport du groupe de travail. IFREMER/Albion Fisheries Research Centre (Mauritius), 23-25 Juillet 1985: 39 pp.

GROWTH PARAMETERS AND MORTALITY RATES OF *Epinephelus fasciatus, Lethrinus nebulosus, Siganus sutor, Naso unicornis and Mugil cephalus* FROM THE COASTAL AREAS OF MAURITIUS AS ESTIMATED FROM ANALYSES OF LENGTH FREQUENCIES

S Rathacharen, A Venkatasami* and *D Degambur

Albion Fisheries Research Centre

ABSTRACT

Growth parameters and mortality rates are used in the management of fisheries resources. In the present study the Length Frequency Distribution Analysis (LFDA 4.01), FISAT and LENA softwares, were utilized to estimate the growth parameters and mortality rates, inter alia: growth rate (K), asymptotic length ($L\infty$), nominal age at which the length of the fish is zero (t_0), total mortality (Z), fishing mortality (F), natural mortality (M), Length at first maturity (Lm50) and Length at first capture (Lc50) for five fish species, viz.: Epinephelus fasciatus, Lethrinus nebulosus, Siganus sutor, Mugil cephalus and Naso unicornis. These fishes are indicator species of the five cluster categories of fish in the lagoon fishery of Mauritius and represent 42.5% of the total catch. The study on the biology of these species was conducted during the period 1990 and 1995.

Keywords: *Epinephelus fasciatus, Lethrinus nebulosus, Siganus sutor, Naso unicornis a*nd *Mugil cephalus,* fisheries resources, lagoon fishery, biological data, fishery-biology, growth parameters, mortality rates, Mauritius.

INTRODUCTION

Very little biological data on such families as Serranidae, Lethrinidae, Siganidae, Mugilidae and Acanthuridae from the coastal areas of Mauritius are available presently. Species of the previously-named families namely *Epinephelus fasciatus, Lethrinus nebulosus, Siganus sutor, Mugil cephalus* and *Naso unicornis* constitute about 42.5% of the annual catch of 1600 tonnes from the lagoon and off-lagoon areas (1208m^2) of Mauritius. The present study gives an estimation of the growth parameters, mortality rates, length at first capture and length at first maturity for the five indicator species of the five cluster category of fish species. Population analysis is concerned more directly with growth rate rather, than the size at various ages, because many problems in fishery assessment are essentially a matter of comparing weight gained by growth against that lost by natural mortality (Gulland 1985). And when considering the effect on an increase in length at first capture. Gulland (1985), suggests that it is important to know the growth rate for a short part of the lifespan of the fish.

MATERIALS AND METHODS

The fish specimens were sampled from the commercial catch for length and weight frequencies 2-3 times weekly at the fish landing stations which were divided into three strata namely South-east, North and West. Samplings were also carried out at the Fishermen's Cooperative Stores, at the markets, at fish exporters' place and other fish sales' outlets. Stratification homogenized the climatic and environmental conditions of each stratum (**Table 1**).

Table 1 Characteristics of the three Strata employed in the Mauritian lagoon fishery catch and stock assessment

Details	North	East / South	West
Boundary	Pte aux Piments to Roches Noires	Poste la Fayette to la Sourdine	Tombeau Bay to Souillac
Coral Reefs	Complete coral reef ridge	Complete coral reef ridge from Poste La Fayette to La Sourdine. However, between La Sourdine and Souillac no coral reef barrier exists. Only cliffs are present.	From Tombeau Bay to Pointe aux Sables continuous coral reefs with large passes. From Pointe aux Sables to Flic en Flac no reef barrier and from Flic en Flac to Souillac coral reef is continuous with passes.
Passes	Many	Many	Few
Environmental factors	Extended northern plateau up to 100 m isobath. In the drop off areas, currents are around three knots	Usually sea rough in the south eastern part	Sewerage pipes, Textile industrial waste
Area of stratum / fishable water	Medium	Large	Small
Others	Highly developed tourism area. Pollution (textile industrial waste, oil from pirogues)	Vigorous oceanic movements of waves	Flic en Flac area - Echinoderm and sand worms present

The length distributions of fish in samples give the simplest index of the composition of the stock from which the catches are being taken and the weight is required for determination of length-weight relation and condition factors (Gulland 1965).

Analyses and processing of length data were conducted using the Length Frequency Distribution Analysis (LFDA Version 4.01), (Holden et al 1995) together with LENA (1994) and FISAT (FAO/ICLARM) packages.

Growth rate $K (1 - L(t)/L\infty)$ declines with time as the length of the fish reaches asymptotic length. Estimation of growth parameters (K, $L\infty$, to) of the Von Bertalanffy growth curve was done followed by definition of grid boundaries using the methods SLCA (Shepherd's Length Composition Analysis) and ELEFAN (Electronic Length Frequency Analysis).

A length-converted Von Bertalanffy catch curve was utilized to estimate total mortality. Natural mortality was calculated using Pauly's M Empirical Formula.

$$Log (M) = 0.0066 - 0.279 Log (L\infty) + 0.6543 Log (K) + 0.4634 Log (T^oC)$$

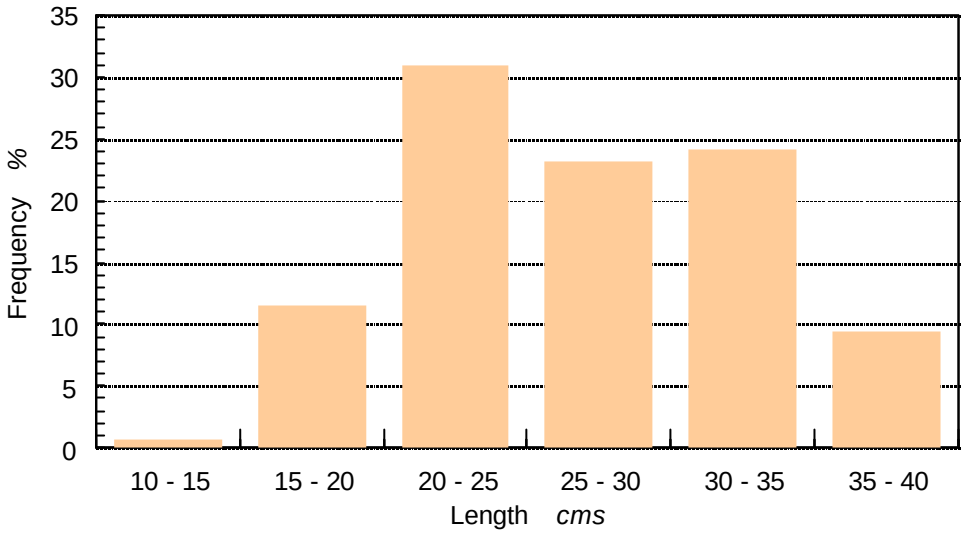
Length at first capture (Lc_{50}) was determined using cut-off length, growth rate values, asymptotic length, natural mortality, total mortality and the selectivity curve. Calculation of Lm_{50} was estimated using length of fish and sexual maturity stages.

RESULTS AND DISCUSSION

Epinephelus fasciatus

For 25 554 *Epinephelus fasciatus* sampled over years 1990 to 1995 the total length varied from 11.0 cm to 39.5 cm. Fischer et al (1984), suggest that the maximum length for this species is 40.0 cm. **Figure 1** gives the length frequency distribution for this species for 1995.

Figure 1 Length frequency distribution for *Epinephelus fasciatus* (1995)



The growth parameter estimates, total mortality coefficients, length at first capture and length at first maturity for *Epinephelus fasciatus* from years 1990 to 1995 are given in **Table 2.**

Table 2 Growth parameters, length at first capture, length at first maturity and mortality rates of *E. fasciatus* for years 1990 - 1995

Year / Growth parameters	1990	1991	1992	1993	1994	1995
K	0.254	0.283	0.257	0.250	0.254	0.177
L_∞	41.29	41.21	42.17	41.14	41.27	40.57
t_o	-0.23	-0.01	-0.10	-0.06	-0.06	-0.04
Z	0.69	0.65	0.62	0.61	0.66	0.60
M	0.56	0.62	0.58	0.56	0.56	0.59
L_{c50}	20.35	20.35	20.35	20.35	20.35	20.35
L_{m50}	26.00	26.00	26.00	26.00	26.00	26.00

The LFDA output using the Shepherd's Length Composition Analysis and ELEFAN for different years with the Von Bertalanffy Growth Curve indicated a growth rate (K) of 0.177 cm per year to 0.283 cm per year and L∞ between 40.57 cm to 42.17 cm**. Figure 2** depicts the score function with maximisation for K and L∞ for *E.fasciatus* length frequency data for 1992 all strata pooled.

Total mortality rate (Z) was estimated using the Catch Curve Mortality Estimator, values of growth rate and asymptotic length. Over the six years, the value of Z varied very little between 0.61 to 0.69.

The natural mortality coefficient (M) using the mean temperature of 24°C and Pauly's M empirical formula averaged to 0.58 for all strata combined over all six years. The fishing mortality was estimated at 0.088. When fishing mortality equals natural mortality (F=M), the species is assumed to be fished at the optimal level of exploitation.

The length at maturity is approximately half the maximum length (L∞) for island populations of Lutjanidae (Grimes 1987). Extending this rule for Serranidae allows the comparison of the length at maturity with the length at first capture. L_{c50} should be greater than L_{m50} so that individuals have the opportunity to reproduce before they are removed from the population. The length at first capture was determined as 20.35 cm at age 2.68 years. L_{m50} for *Epinephelus fasciatus* was 26 cm at age 3.96 years which was determined using the Von Bertalanffy equation. When length at first capture is greater than L_{m50}, effort controls are less important and over fishing is unlikely to occur. Where the reverse is true, careful control of the amount of effort exerted is required.

Conversion of length to age was estimated from the Von Bertalanffy equation using the formula:

$$t = (1/k)\ Log_e\ L¥/L¥ - Lt) + t_o.$$

Figure 2 Score function for *E. fasciatus* (1992)

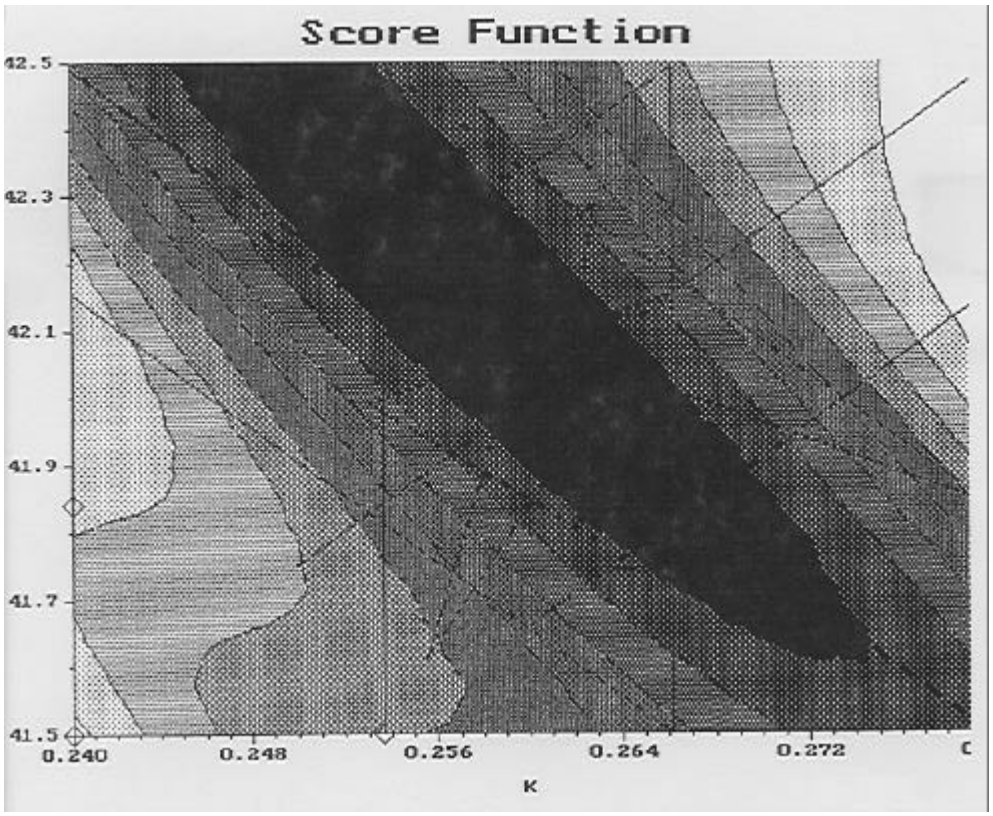


Table 3 gives the estimated weight length-wise with corresponding age.

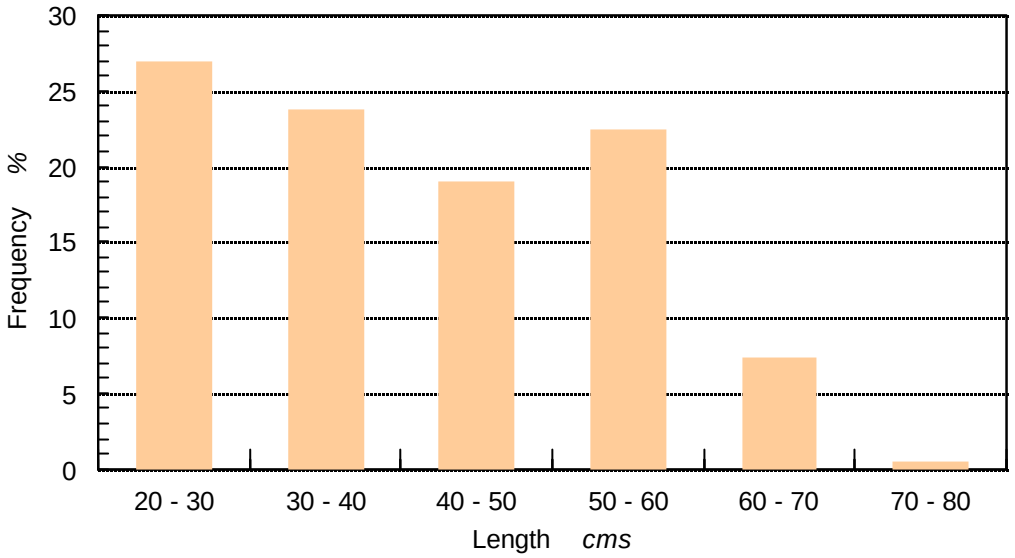
Table 3 Estimated weight of *E. fasciatus* lengthwise with corresponding ages

Length *cm*	Estimated Weight *g*		Age *Years*
10	32	30	1.05
15	79	78	1.75
20	151	153	2.61
25	250	260	3.70
30	378	399	5.19
35	535	575	7.56
40	724	788	13.98

Lethrinus nebulosus

For 15,381 of *L. nebulosus* sampled, the total length varied between 18.0 cm and 70.0 cm. Fischer and Bianchi (1984) suggest that the maximum length for this species is 87 cm and its common length is 60 cm. The total weight ranged from 100g to 5700g. **Figure 3** shows the length frequency distributions for 1995.

Figure 3 Length Frequency Distribution for *L. nebulosus* (1995)



The growth parameter estimates and mortality rates for *L. nebulosus* from years 1990 to 1995 are given in **Table 4.** LFDA output using the SLCA with the Von Bertalanffy Growth Curve indicated a growth rate (K) of 0.204 cm per year in 1994 and 0.273 cm per year in 1992. Asymptotic length was in the range of 78.26 cm to 85.00 cm. **Figure 4** gives the Shepherd Length Composition Analysis for 1992.

Table 4 Growth parameters and mortality estimates for *Lethrinus nebulosus* for years 1990-1995

Year / Growth parameters	1990	1991	1992	1993	1994	1995
K	0.235	0.205	0.273	0.259	0.204	0.227
L∞	78.26	81.65	85.00	80.51	82.00	78.46
To	-0.61	-0.90	-0.74	-1.00	-0.50	-0.01
Z	0.67	0.89	0.74	0.87	0.68	0.688
M	0.38	0.41	0.53	0.48	0.41	0.51

The total mortality coefficient (Z) of *L. nebulosus* was estimated using the Catch Curve Mortality Estimator together with values of K and L∞. Total mortality was estimated at 0.67 to 0.89 per year over the six years.

The value of natural mortality coefficient (M) was estimated at 0.45. Pauly's formula indicates that small fish and fast-growing species have high natural mortalities. High values of M are noted if the ambient ecosystem is warmer. It is also noted that same species may have different natural mortality rates in different areas depending on the density of predators and competitors whose abundance is influenced by fishing activities (Sparre 1992).

The fishing mortality coefficient (F) was estimated at 0.34. Gulland (1985) suggests that fishing mortality coefficient is proportional to the amount of fishing, or fishing effort. The length at capture for the 6 years of study was 26.133 cm at age 1.27 years using the Von Bertalanffy equation for conversion of length to age. The length at first maturity was 29.5 cm at age 1.58 years.

Figure 4 Shepherd Length Composition Analysis for *L. nebulosus* (1992)

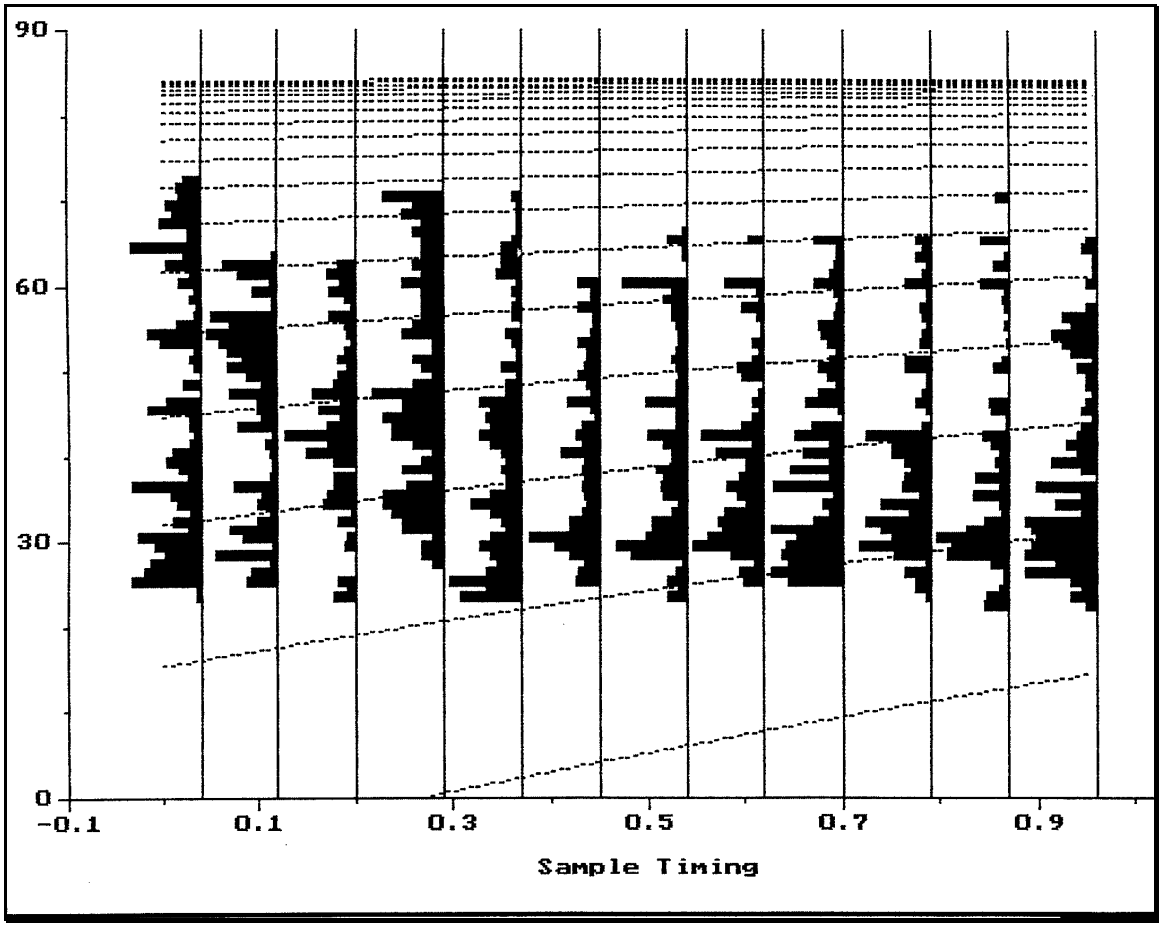


Table 5 Length at first capture and length at first maturity Estimates (1990-1995**)**

Year	1990	1991	1992	1993	1994	1995
Lc50	25.4	27.3	25.0	30.0	25.4	23.7
Cut-off length	35.0	32.0	32.0	32.0	30.0	28.0
Mean length	43.4	37.6	41.3	43.0	38.0	40.7
Standard deviation	10.16	11.30	12.42	11.78	10.30	12.58
Lm_{50}	29.5	29.5	29.5	29.5	29.5	29.5

Table 6 gives estimation of weight and age at each corresponding length.

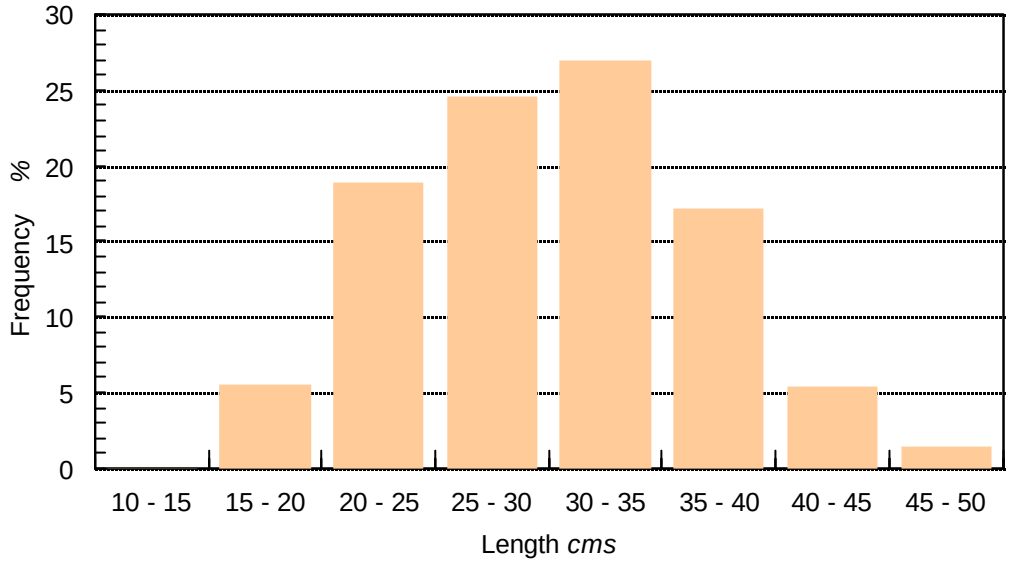
Table 6 Estimated weight and age of *L. nebulosus* lengthwise

Length *cm*	Estimated	
	Weight *g*	Age *Yrs*
20	111	0.76
30	301	1.62
40	612	2.68
50	1058	4.02
60	1657	5.88
70	2421	8.91
80	3363	18.36

Siganus sutor

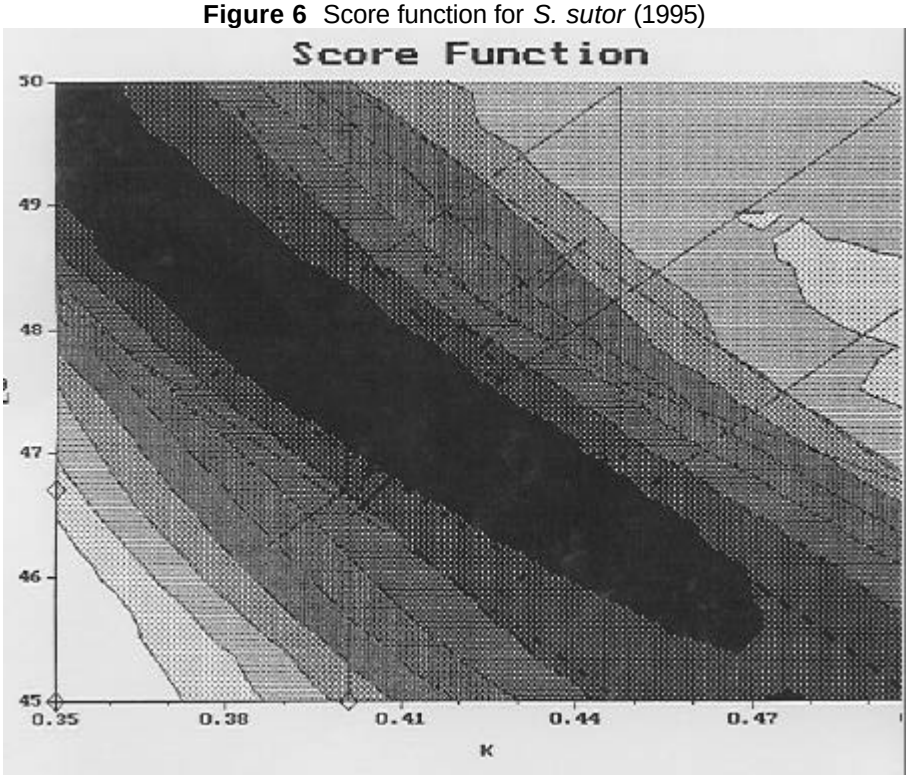
16 811 cordonniers were sampled during period covering 1990 to 1995 and the total length recorded varied from 12.0 cm at 51.0 cm while the weight of fish ranged between 50 g and 1, 650 g. Fischer et al 1984 indicate that the maximum length of this species is 45.0 cm, whereas the common length is 30.0 cm. **Figure 5** gives the length frequency distribution obtained in 1995.

Figure 5 Length Frequency Distribution for *S. sutor* (1995)



The Length Frequency Distribution Analysis using the SLCA with the Von Bertalanffy Growth Curve indicated a growth rate, K, of 0.412 cm per year to 0.751 cm per year. Analysis gives an indication that this species grows towards asymptotic length faster than the two previously analysed species. Analysis involved maximization of a score function in order to measure goodness of fit.

Figure 6 Score function for *S. sutor* (1995)



In **Figure 6**, a contour plot with appropriate range of growth rate and asymptotic length for 1995 showed that the maximum of the score function for *S. sutor* was in a banana-shaped region. The asymptotic length ranged between 43.14 cm to 53.84 cm with an average of 48.45 cm. The nominal age (t_o) varied between -0.25 to -0.90. Total mortality rate, Z, was estimated at 1.46 to 1.83 with a mean of 1.60.

The natural mortality coefficient (M) was estimated through FISAT using Pauly's M empirical formula and 24°C as the mean temperature at the surface. The value of natural mortality was 1.01. An estimate of 0.59 as the fishing mortality coefficient per year was obtained. Fast growing species such as cordonnier have high natural mortalities (**Table 7**).

Table 7 Growth parameters and mortality estimates for *Siganus sutor* for years 1990-1995

Year / Growth parameters	1990	1991	1992	1993	1994	1995
K	0.466	0.564	0.629	0.751	0.619	0.412
L∞	53.84	43.14	49.68	47.54	49.21	47.29
To	-0.44	-0.64	-0.82	-0.25	-0.90	-0.27
Z	1.83	1.75	1.81	1.60	1.46	1.16
M	0.86	1.03	1.07	1.21	1.06	0.82

The length at first capture L_{c50} was estimated at 25.46 cm corresponding to 0.75 per year using cut off length, growth rate values, L∞, m, selectivity curve and total mortality. The length at first maturity was 18.0 cm at age 0.71 yrs.

Table 8 Length at first capture and length at first maturity estimates for *Siganus sutor* (1990-1995)

Year	1990	1991	1992	1993	1994	1995
Lc50	27.9	23.8	24.6	25.2	25.3	26.0
Cut off Length	32.0	30.0	30.0	27.0	32.0	30.0
Standard deviation ±	4.58	5.89	5.28	4.58	5.97	6.55
Mean Length	28.9	28.6	28.8	32.9	29.9	29.7
Lm_{50}	18.0	18.0	18.0	18.0	18.0	18.0

Estimated weight to corresponding ages for *S. sutor* are given in **Table 9**.

Table 9 Estimated weight and age for *Siganus sutor* lengthwise

Length *mm*	Estimated Weight *g*	Age *years*
100	33.4	0.133
150	80.4	0.375
200	149.4	0.657
250	241.9	0.992
300	358.7	1.412
350	500.4	1.963
400	667.7	2.772
450	861.1	3.15
500	1081.2	3.5

Naso unicornis

The total length of 14 894 licornes sampled varied between 20.0 cm and 73.0 cm, while the total weight ranged between 200g and 5700g. The maximum length for this species is 70.0 cm whereas the common length is 50 cm (Fischer et al 1984). The LFDA output using the SLCA with the Von Bertalanffy Growth Curve indicated a growth rate of 0.106 cm per year to 0.188 cm per year. The average growth rate stands at 0.163 cm per year implying that Naso unicornis grows slowly towards asymptotic length. A slow growth rate has also been indicated for this species in Palau, Oceania (Fish Base 1996) where K = 0.14 cm per year for that country. Maximisation of a score function in order to measure goodness of fit for Naso unicornis is given in **Figure 7** where asymptotic length ranged between 78.02 cm and 83.44 cm with an average of 81.03 cm. The total mortality and natural mortality coefficients were estimated at 0.543 and 0.40 respectively. The value of the length at first capture Lc50 was 27.42 cm at age 1.9 yrs using cut off length, growth rate values, $L\infty$, natural mortality coefficient, , selectivity curve and total mortality coefficient. Lm50 was estimated at 28.5 cm at age 2.03 years (**Table 10**).

Figure 7 Score function for *N. unicornis* (1995)

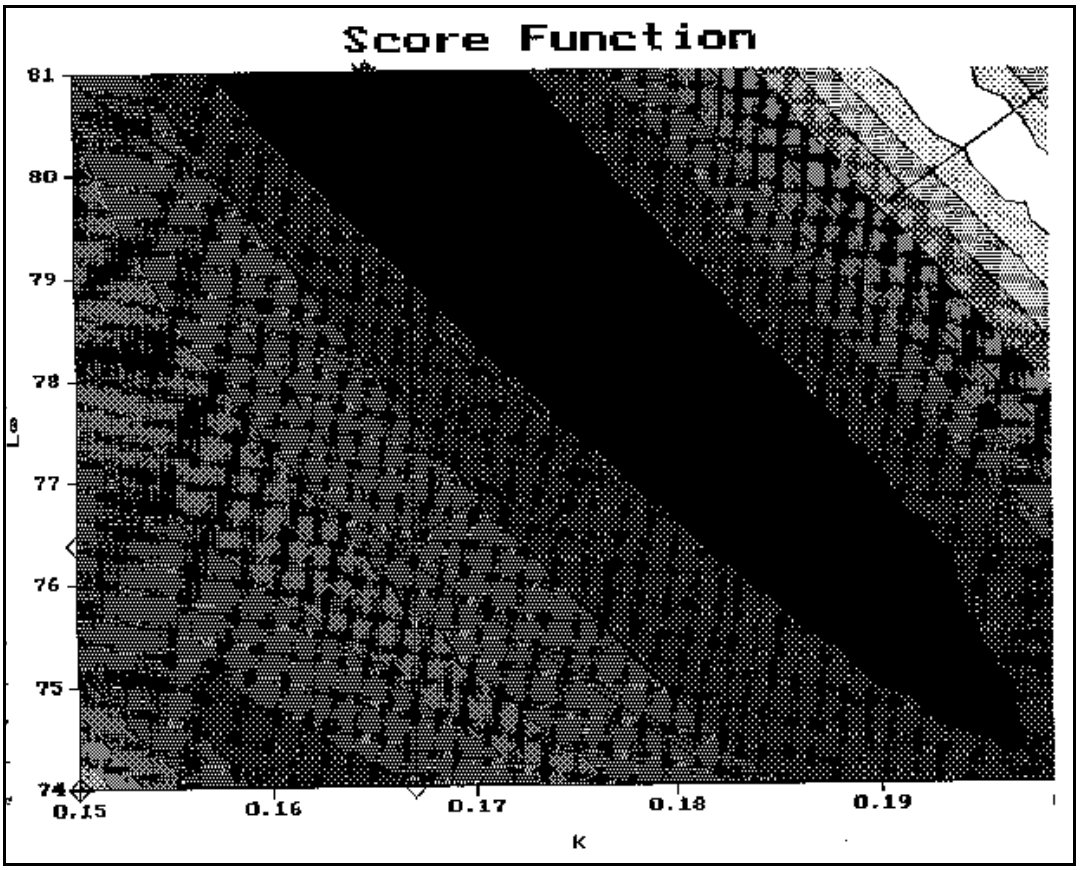


Table 10 Length at first capture estimates (1990-1995)

Year	1990	1991	1992	1993	1994	1995
Lc50	27.80	28.90	28.30	-	26.50	25.60
Cut off Length	31.0	32.0	33.0	32.0	33.0	31.0
Standard deviation ±	13.07	11.55	9.37	3.13	11.38	10.76
Mean Length	47.3	50.3	42.7	61.3	45.6	43.5
Lm_{50}	28.5	28.5	28.5	28.5	28.5	28.5

Table 11 gives the estimated weight and corresponding age lengthwise for *Naso unicornis*.

Table 11 Estimated weight and age for *Naso unicornis* lengthwise

Length *mm*	Estimated Weight *g*	Age *years*
200	139.2	1.06
300	411.1	2.17
400	886.1	3.52
500	1607.9	5.24
600	2616.2	7.64
700	3948.3	11.62
800	5639.6	13.50

Mugil cephalus

For 12,783 *Mugil cephalus* sampled over the years 1990 - 1995, the total length ranged between 23.0 cm and 71.0 cm, while the total weight varied between 200g to 3500g. Fischer et al 1984 suggests that the maximum length for this species is 90 cm and the common length is 35 cm. **Figure 8** gives the length frequency for 1995.

Figure 8 Length Frequency Distribution for *M. cephalus* (1995)

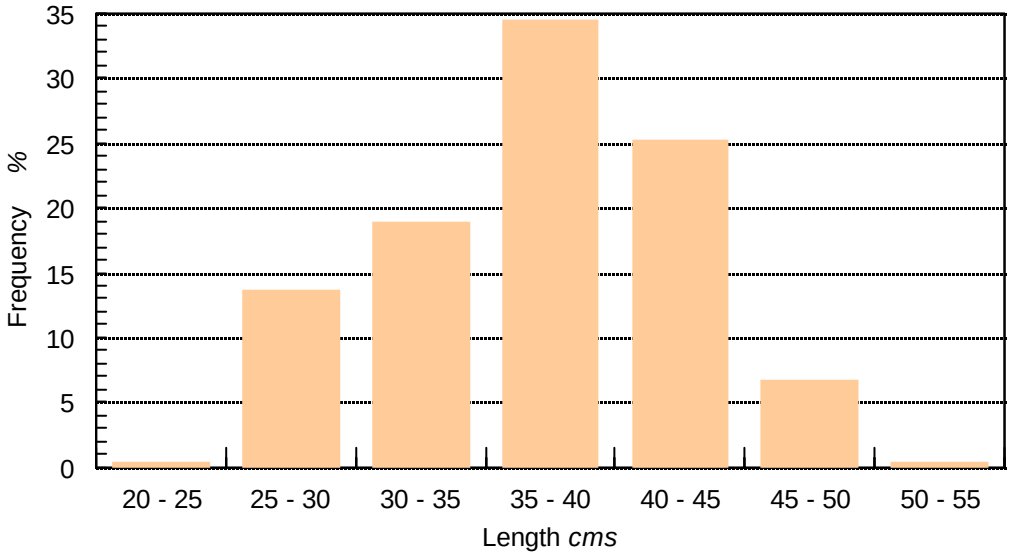


Table 12 gives the growth parameter estimates and mortality coefficients for *Mugil cephalus.*

Table 12 Growth parameters and mortality rates of *Mugil cephalus* for years 1990-1995

Year / Growth parameters	1990	1991	1992	1993	1994	1995
K	0.313	0.308	0.175	0.207	0.312	0.269
L_∞	90.00	83.69	86.86	87.86	88.43	85.00
t_0	-0.57	-0.79	-0.38	-0.78	-0.52	-0.61
Z	1.46	1.28	1.21	1.62	1.38	1.65
M	0.63	0.58	0.39	0.44	0.57	0.53

The growth rate K was between 0.175 and 0.313 cm per year with an average of 0.264 cm per year. The asymptotic length, $L\infty$ varied between 83.69 cm and 90 cm. The average asymptotic length over the years was 86.97 cm. Total Mortality rate, Z, was calculated by the Catch Curve Mortality Estimator using the values of the growth rates and asymptotic length. During the period under study Z varied between 1.20 and 1.30 with a mean value of 1.21. Natural Mortality M was calculated from the Pauly's M empirical formula using growth rate, asymptotic length and the mean temperature of 240C. M was estimated between 0.39 to 0.63 per year for the six years and averaging to 0.523 for all strata combined over the years. The fishing mortality was estimated at 0.69. There seems to be no difference between the fishing mortality and the natural mortality,even though the natural mortality is slightly lower than the fishing mortality.

Length at first capture estimates were made for Mugil cephalus, using the selectivity curve, K values, $L\infty$, cut-off lengths, M and Z. In general the length at which 50% of the individuals are vulnerable to gear, Lc50 should be greater than the length at first maturity so that individuals have the opportunity to spawn before they are captured. The length at first capture Lc50was determined as 33.30 cm at age 1.22 years for this species. The length at first maturity Lm50 was 30.00 cm at age 0.99 years (**Table 13**).

Table 13 Length at first maturity and length at capture estimates for *Mugil cephalus* (1990-1995)

Year	1990	1991	1992	1993	1995
Lc50	35.9	36.40	31.70	30.00	32.30
Cut off Length	39.0	39.0	39.0	36.0	42.0
Mean Length	54.2	49.4	43.5	43.7	36.8
Standard deviation ±	7.7	9.19	11.47	3.66	5.57
Lm50	30.0	30.0	30.0	30.0	30.0

The different parameter estimates made little difference to the estimated weight and age of fish at each length (**Table 14**).

Table 14 Estimated weight and age for *Mugil cephalus*

Length *mm*	Estimated weight *g*	Age *years*
200	172.9	0.38
300	492	0.99
400	1033.6	1.72
500	1836.1	2.63
600	2942.1	3.82
700	4379.1	5.57

Estimated age length-wise for the five fish species studied is summarised in **Table 15.**

Table 15 Estimated age length-wise for *Epinephelus fasciatus*, *Lethrinus nebulosus*, *Siganus sutor, Naso unicornis* and *Mugil cephalus*

Species	Length (*cm*)							
Age (*years*)	10	20	30	40	50	60	70	80
E.fasciatus	1.05	2.61	5.19	13.98	-	-	-	-
L.nebulosus	-	0.76	1.62	2.68	4.02	5.88	8.91	18.36
S.sutor	0.13	0.66	1.42	2.77	3.50	-	-	-
N.unicornis	-	1.06	2.17	3.52	5.24	7.64	11.62	13.5
M.cephalus	-	0.38	0.99	1.72	2.63	3.82	5.57	-

CONCLUSION

Preliminary growth parameter estimates and mortality coefficients for the five commercially important lagoon fish, inter alia, *Epinephelus fasciatus*, *Lethrinus nebulosus*, *Siganus sutor*, *Naso unicornis* and *Mugil cephalus* have been established. The growth rate for *Epinephelus fasciatus*, *Lethrinus nebulosus* and *Naso unicornis* are low as compared to the fast growing species, viz. *Mugil cephalus* and *Siganus sutor*. Asymptotic length was more than the maximum length for four species except for *Siganus sutor*. This indicates that the mortality rate suffered by the four other species is very high. Comparison of length at first capture and length at first maturity for *Epinephelus fasciatus*, *Naso unicornis* and *Lethrinus nebulosus* shows that these individuals do not have the opportunity to reproduce before they are removed from the population. Establishment of growth parameter estimates and mortality rates may eventually lead to Virtual Population Analysis and stock assessment of these lagoon species of Mauritius.

ACKNOWLEDGEMENT

The authors would like to thank Mr. M. Munbodh, Principal Fisheries Officer for the usual encouragement and provision of logistics at the Albion Fisheries Research Centre to undertake this study.and Dr Chris Mees of MRAG (UK) for his valuable collaboration. Gratitude is expressed to Mr. D. Goorah, Divisional Scientific Officer for initiating this work and to Mrs. D. Jinerdeb for typing this paper.

REFERENCES

CARPENTER KE. 1996. *Fishbase*.

FISHER W. and BIANCHI G. *FAO species identification sheets for fishery puposes* WIO (Fishing Areas 51), Vol. II 1984, FAO/UN.

FRIMODT C. *Multilingual illustrated guide to the World's commercial warm water fish*, 1995. Fishing News Books, Osney Mead, Oxford, England, 215 p.

GULLAND JA. 1985. *Fish stock assessment: A manual of basic methods*. Vol. I. FAO/Wiley. 223p.

GULLAND JA. 1969. *Manual of methods for fish stock asses*sment. Part I. FAO/UN. 154p.

HOLDEN S, KIRKWOOD G and BRAVINGTON MV. 1995. *Length Frequency Distribution Analysis*, Version 4.01. MRAG Ltd UK.

LAEVASTU T. 1965. *Manual of methods in fisheries biology*. FAO/UN.

LAEVASTU T. 1965. *Manual of methods in fisheries biology*, 1965. Fascicule 9. Section 4. Research on fish stocks, 51p.

MEES CC. 1996. *Assistance in the analysis of Mauritian lagoon fishery data*. MRAG Ltd. UK. 65p.

MEES CC. 1996. *Management of multi-species tropical marine fisheries*. MRAG Ltd, UK. 193p.

SANDERS MJ, SPARRE P and VENEMA SC. Eds. 1988. *Proceedings of the workshop on assessment of the fishery resources in the SWIO*. FAO/UNDP: RAF/79/065/WP/41/88/E. 277p.

SPARRE P and VENEMA SC. 1992. *Introduction to tropical fish stock assessment*. Part I & II. FAO/UN.

EVALUATION OF THE PERFORMANCE OF THE SMALLHOLDER GOAT PRODUCTION SYSTEM IN MAURITIUS

D Saddul, MM Seenevassen Pillay, RK Ramnauth, R Fakim, R Lam Sheung Yuen, G Saraye, P Toolsee* and *AA Boodoo

Agricultural Research and Extension Unit

ABSTRACT

A study to assess the performance of village goats was undertaken from April 1997 to June 1999 in selected localities in 5 districts. The smallholder farming system was described. Poor husbandry practices and single flock management were characteristic of the system. Kidding data were collected for 419 does of unknown parity (multiparous does) over three reproductive cycles

A total of 550 kiddings was recorded with 883 kids (469 males, 414 females). 42 female kids born to 39 multiparous does were monitored till they kidded for the first time(primiparous does). Overall kidding percentage of multiparous does was 78.8% and overall litter size was 1.6, compared to a litter size of 1.04 for primiparous does. Overall kidding interval was 8.1±0.2 months, indicating the potential for 3 kiddings in two years. Average weight of does at first kidding was 12 ± 0.5 months, indicating their ability to reach sexual maturity early. However, body weight of does at first kidding was low, 15.4±0.5 kg, implying that the does were mated at a low body weight. Overall mortality in kids up to 3 months of age born from multiparous does was 15.9 % and was highest among triplets. Causes of death were unknown.

Keywords: goats, smallholders, farming system, management practices, Mauritius

BACKGROUND

Goat keeping in Mauritius is a part-time activity involving mainly the women folk. It represents an additional source of revenue to the farmer's main income as well as a cash reserve for periods of financial difficulties. Goat meat is consumed by all religious groups and the demand for fresh meat is at its highest during the end of year festivities and during special occasions, such as religious ceremonies and weddings.

However, the goat sector has witnessed a drastic decline from 72 696 head in 1983 to 19 800 head in 1996, with a corresponding decline in the number of goat farmers from 16 329 in 1983 to about 4 000 in 1996. Local production of fresh goat meat has dropped from 84.8 tonnes in 1992 to 51.6 tonnes in 1997. The carcass weight of local goats in 1992 was 6 kg/hd compared to a carcass weight of 7.2 kg/hd in 1997. On the other hand, importation of live goats for slaughter at the abattoir has witnessed an overall increase from 41.6 tonnes carcass in 1992 to 68.4 tonnes carcass in 1997. The carcass weight of imported goats (16.5kg) is more than twice that of local goats.

The low carcass weight of local goats indicates that either immature young goats are being slaughtered, or the village goats are of poor productivity under prevailing rearing conditions. The village goats have always been referred to as being poor performers. This is due to the combined effect of poor husbandry practices, which is characteristic of the system and a certain level of inbreeding in the flocks since there has not been introduction of new blood for the last 10 years. However, to date, there are no data to quantify the poor performance of the village goats.

Objective

The objective of this study, therefore, was to describe the production systems in this sector and quantify the performance of the animals under village conditions. Thus, knowledge of some reproductive parameters will help to identify constraints (management, genetic or other factors) associated with the performance of the animals. This will subsequently enable the development of a strategy for improving the management conditions and, hence, the performance of the goats for better carcass weight and quality of the meat.

MATERIALS AND METHODS

The study was conducted in selected localities in the districts of Black River, Rivière du Rempart Flacq, Plaines Wilhems and Pamplemousses (Table1), where there is a concentration of goat farms. Farms were selected randomly to have a sample size representing 3.1% of the total goat farms in the island. Selected farms that were inaccessible and farmers who were not willing to participate were replaced during the sampling procedure. Thus a total of 124 goat farms were selected.

Table1 Localities selected for the study

District	Selected localities
Black River	Canot, Petite Rivière, Gros Cailloux, Albion, Beau Songes and Bambous
Rivière du Rempart	Plaines des Roches, Roche Noires
Flacq	Bramsthan, Ecroignard, Poste de Flacq, Quatre Cocos
Plaines Wilhems	Palma, Bassin, Henrietta
Pamplemousses	Fond du Sac, Vale

The goats in the study were mostly of local breed (non-descript), with some traces of exotic breed, especially Jamna Pari. All breeding does that were on the farms were selected, except for farms with flock size exceeding 25 head, where 8 breeding does were selected randomly. The does were identified using numbered plastic tags and were monitored over three kiddings. No reliable information was available on the parity of the does. Each farm was visited at fortnightly intervals until the first kidding to ensure collection of precise kidding date and kid details. After the first kidding the farms were visited at monthly intervals for weighing of kids and data collection on the system of production.

The following data were collected:

a) Date of kidding, litter type (single or multiple births), abortions (actually observed by the farmer), death and sale of does

b) Birth weight, sex, stillbirths, and body weight at monthly intervals, sale and death of kids (approximate age and possible cause)

Birth weight was recorded within 48 hours. However, given that farmers do not normally record kid birth weight, it was possible to obtain birth weight data for only 125 kids when visits were effected. Monitoring of 42 female kids born to the 39 multiparous does was continued until they reached sexual maturity, got mated and kidded for the first time (primiparous does). The kidding parameters of their progenies were also monitored. The parameters determined were:

For the does - kidding percentage, litter size, kidding interval, age and weight of does at first kidding

For the kids – birth weight, mortality rate (birth to 90 days of age and after 90 days, respectively). The parameters were determined by sex and litter type.

Data collection started in April 1997. A total of 419 does of unknown parity (multiparous does) and 42 primiparous does were monitored. The study ended in June 1999 with 120 does.

RESULTS

Farm characteristics

Rearing system

Stall-feeding was the main system of goat rearing on 89.5% of the farms; while on 6.5% of farms only grazing was practised on marginal lands. On only 4% of the farms, a combination of stall feeding and grazing was practised. On most farms, the animals were reared traditionally with minimum inputs in the form of supplementary feeds or parasite control. Under stall fed systems, the bucks were tethered to poles in the shed. This was done mostly to avoid bullying in the flock. The practice of weaning as well as record keeping was inexistent on all the farms.

The practice of supplementation

On most of the farms (95.2%), supplementary feed was not given to the animals, while on 4.8% of the farms cow feed (a dairy concentrate containing 16% crude protein) was occasionally fed to the goats, in periods of fodder shortages or when the fodder was of poor quality.

Reproductive management

On all the farms, the flocks consisted of goats of all ages and they were kept as a single flock, the bucks running continuously with the does. Single flock management can be explained by the fact that the farmers were reluctant to devote additional time and to incur additional costs to improve over the existing farm infrastructure (i.e., putting up partitions in the shed to accommodate different groups of animals). There was thus no control over breeding, resulting in indiscriminate mating between animals that were closely related. Inbreeding among these flocks was therefore inevitable because the same buck was used for a long period of time. Moreover, there was no introduction of new blood in the form of buck or doe replacement from other farms.

Doe Performance

From the 419 multiparous does 330 kiddings were obtained during the first reproductive cycle. A total of 550 kiddings were obtained during the three reproductive cycles under study. Thus, a total of 883 kids (469 males, 414 females) born alive have been recorded. 42 primiparous does also kidded, giving 44 kids.

Kidding percentage

bThe kidding percentage of multiparous does (i.e. does kidding per does exposed to bucks) in the 5 districts is shown in Table 2.

Table 2 Kidding percentage of multiparous does in the 5 districts

Region	No. of does		Kidding %
	Exposed to bucks	Kidded *	
Black River	113	91	80.5
Rivière du Rempart	116	89	76.7
Flacq	108	92	85.2
Plaines Wilhems	42	31	73.8
Pamplemousses	40	27	67.5
Overall kidding % **	419	330	78.8

* During the first reproductive cycle ** Based on 330 kiddings

The overall kidding percentage of 78.8% is considered satisfactory under the traditional farming system. With the exception of the Pamplemousses and Plaines Wilhems regions where a relatively low kidding percentage was recorded, there was not a wide variation in the kidding percentage in the other regions. The highest kidding percentage was observed in the Flacq region.

Litter size

The litter size of multiparous does (i.e. live kids born per doe kidding) for the different regions is shown in Table 3

Table 3 Litter size of multiparous does for the three reproductive cycles

Region	Litter size			
	In the 3 reproductive cycles			Overall [1]
	1st	2nd	3rd	
Black River	1.6	1.9	2.1	1.7
Rivière du Rempart	1.6	1.8	1.8	1.7
Flacq	1.4	1.6	1.6	1.5
Plaines Wilhems	1.6	1.7	1.5	1.6
Pamplemousses	1.5	1.5	NA	1.5
Overall[2]	*1.5*	*1.7*	*1.8*	*1.6*

[1] Based on total kids born over the three reproductive cycles

[2] based on all 550 kiddings NA – not available

An overall litter size of 1.6 is indicative of the existence of multiple births and of the good reproductive potential of local goats, despite the lack of supplementary feeding. It was observed that overall litter size improved from 1.5 to 1.7 after the second reproductive cycle during the study. This pattern was consistent for all the regions except Pamplemouses, and was more pronounced in the Black River and Rivière du Rempart regions where the maximum litter size recorded was 1.9 and 1.8 respectively. In the case of primiparous does, out of 42 does, only 2 gave twins and the litter size was 1.04. This was lower than that of multiparous does.

Incidence of multiple births

Table 4 shows the proportions of different types of litter obtained.

Table 4 Incidence of multiple births from multiparous does

Litter type	No. of kiddings	%
Single	257	46.7
Twins	251	45.6
Triplets	40	7.3
Quadruplets	2	0.4
Total kiddings	550	

There was a high percentage of single and twin births as compared to triplets and quadruplets. The level of twinning was almost similar to that of single litter. This is a good indication of the prolificacy of the village goats.

Kidding interval

Data on kidding interval (number of days between 2 successive kiddings) for the does in the different regions are presented in **Table 5**..

Table 5 Kidding interval (*months*) for does in the different regions

Region	*N*	*Min.*	*Max.*	*Mean*	S.E ±
Black River	69	5.5	13.4	8.7	0.2
Rivière du Rempart	67	5.4	12.1	7.4	0.2
Flacq	24	6.3	17.2	8.5	0.5
Plaines Wilhems	13	5.4	14.2	8.0	0.7
Pamplemousses	2	6.0	7.3	6.7	0.6

n: number of intervals SE±: standard error

The overall kidding interval for all regions was 8.1 ± 0.2 months, implying the possibility of achieving three kiddings over a two-year period. However, there was a wide variation in the kidding interval for the different regions, (with Pamplemousses having the smallest interval) despite the fact that the bucks ran continuously with the does throughout the year.

Liveweight and age of primiparous does

The mean liveweight and age of does at first kidding are given in **Table 6.**

Table 6 Mean liveweight and age of primiparous does at kidding

Region[1]	*n*[2]	Wt. at first kidding *kg*	*n*	Age at first kidding *months*
Black River	22	15.8 ± 0.7[3]	22	12.0 ± 0.6
Rivière du Rempart	6	15.0 ± 1.0	9	11.7 ± 0.4
Flacq	8	13.1 ± 0.6	5	11.7 ± 0.7
Pamplemousses	1	NA	1	13.6

[1] data for Plaines Wilhems were not available [2] *n* number of animals [3] mean ± SE NA - not available

On an average, the first kidding occurred at the age of 12.1 ± 0.4 months, with a mean post-kidding weight of 15.5 ± 0.5kg. This implies that the young females were mated as from an estimated age of 7.2 ± 0.4 months and at a low body weight. The weight at first kidding was higher in the Black River and Rivière du Rempart regions as compared to Flacq.

Kid performance

Birth weight

Of the 883 kids born from multiparous does in the study, birth weight data were recorded for 125 kids and are shown in **Table 7**.

Table 7 Average birth weight of kids

Kids from does	Litter type	Male	Female
Multiparous	Single	2.1 ± 0.5 (n=21)	1.8 ± 0.6 (n=14)
	Twins	2.0 ± 0.7 (n=40)	2.1 ± 0.5 (n=40)
	Triplets	1.5 ± 0.1 (n= 5)	1.3 ± 0.2 (n= 5)
Primiparous	Single	1.9 ± 0.6 (n=12)	2.1 ± 0.6 (n= 4)

The birth weight of single and twin kids (male and female) born from multiparous does was 2.0±0.3kg while that of triplets was 1.5±0.02 kg. There was no significant sex effect in the birth weight of kids born from either multiparous or primiparous does. A significant litter type effect ($P<0.05$) was observed among kids born from multiparous does. Kids born as singles and twins had significantly higher birth weight than kids born as triplets (**Table 6**). However, there was no significant difference

between the birth weight of single kids born from multiparous does and that of kids born from primiparous ones.

Kid mortality rate

Death in kids was grouped from birth up to 3 months and over 3 months of age, respectively. Data for the different regions have been pooled and are shown in **Table 8** by each litter type and sex for kids up to 3 months of age, born from multiparous does.

Table 8 Mortality rate (%) by sex and litter in kids up to 3 months of age born from multiparous does

Litter type	Total kids			Male kids		Female kids	
	Born alive	Dead[2]	% [2]	Dead	% [1]	Dead	% [1]
Single	256	45	17.6	33	12.9	12	4.7
Twins	499	53	10.6	30	6	23	4.6
Triplets	120	38	31.7	14	11.7	24	20
Quadruplets	8	4	50	4	50	0	0

[1] based on number of kids born per litter type [2] male and female kids for each litter type

Overall mortality rate among kids up to the age of 3 months, born form multiparous does (sex and litter type confounded) was as high as 15.9%. Higher mortality rate was obtained among kids born as quadruplets and triplets compared to kids born as singles and twins. However, a higher mortality rate was observed in kids born from single litter compared to kids born as twins. This could not be explained as post-mortem examination was not done on kids in the village farms. The overall mortality rate in kids over 3 months of age was 6.5%, and, as expected, was much lower than in kids under 3 months old. Mortality rate of kids up to 3 months of age, born from primiparous does was 35%. It was 12.5% for kids over 3 months.

DISCUSSION

The reproductive performance of a flock is characterised by the age at first kidding, kidding percentage, litter size, kidding interval and the number of years the animals are capable of reproduction (Steinbach 1988). The last characteristic could not be determined in this study due to its short duration.

An average age at first kidding of 12.1 ± 0.4 months is indicative of the ability of local goats to reach sexual maturity early. This is comparable to findings on local goats under traditional village management systems in Malaysia, where an average first kidding age of 13 months was obtained (Peters et al 1981). However, early kidding indicates the existence of indiscriminate mating of young kids, which were still in the growing phase and as such had not attained appropriate body weight at service time. This could have set backs on body development, reproductive performance and lifetime productivity of the does.

The overall kidding percentage of 78.8% under traditional village farming system is satisfactory. This can be improved through the practice of supplementation, particularly during the pre-mating period (flushing). Supplementation will also contribute to improve the body condition of the does and subsequently result in better kidding performance.

An overall litter size of 1.6 indicates the good prolificacy of the goats. Does of first parity produced mainly single litters whereas in multiparous does there was a considerable proportion of twins (45.6%). The improvement in overall litter size from 1.5 to 1.7 that was observed after the second reproductive cycle was associated with an improvement in the body condition of the does during subsequent kiddings.

Large litters are very often associated with high kid mortality rate, particularly during the first three months following birth. This was observed in the case of quadruplets and triplets born from

multiparous does with a mortality rate of 50% and 31.7%, respectively. This could be associated to the relatively low birth weight observed of triplet kids (1.5kg) compared to about 2.0kg in the case of single and twin kids. Low kid birth weight could be the outcome of single flock management whereby animals are inadequately fed irrespective of the litter they carry. Mortality rate in kids up to 3 months of age born as single and twins from multiparous does (17.6% and 10.6%, respectively) was also high and this could possibly be attributed to bullying by big animals, poor milk production by the does, unfavourable hygienic conditions in the shed for the kids or higher susceptibility of the kids to internal parasite infestation in a system where prophylactic measures were inexistent. A study conducted in 1996 (Jugessur et al. 1998 in press) to evaluate the level of infestation of village goats with endoparasites in varying climatic conditions showed a significant level of internal parasitism in adults and kids.

With a gestation period of 150 days and an oestrus cycle of 17 days, a minimum kidding interval of 167 days can be expected before a female becomes pregnant in the first day of the cycle (Filius *et al*. 1986). Under a system where the bucks run continuously with the does, the kidding interval is expected to be shorter than what was actually observed (8.1± 0.2 months). This is possibly due to the manifestation of anoestus either due to lactation or due to the does not having appropriate body condition after kidding for successful conception. Nonetheless, the kidding interval of 8.1 ± 0.2 months indicates the ability of the goats to breed throughout the year as well as the potential of attaining 3 kiddings in two years on most farms. There is a need for supplementary feeding during the whole reproductive period to ensure that the does attain adequate body condition at mating and a rapid recovery of body condition post-kidding.

CONCLUSION

The results show the potential of village goats in a system characterised by traditional and poor husbandry practices. Single flock management together with poor reproductive practices resulted in poor body weight of does at first service and indiscriminate breeding of closely related animals. However the overall kidding percentage of 78.8% and litter size of 1.6 are indicators of the potential for improvement in this system of production. Farmer education is therefore necessary and incentive packages will help in the adoption of improved husbandry practices.

ACKNOWLEDGEMENTS

We are grateful to the goat farmers in the regions of Black River, Rivière du Rempart, Flacq, Plaines Wilhems and Pamplemousses for their invaluable support during the study and for providing us the relevant information. We are also grateful to the following persons for having provided their support during the study: the Biometrician, R.K.Ramnauth, the Assistant Research Scientist, V.Vally, the Extension Officer, P. Dobee and the labourers of the Agricultural Services and AREU.

REFERENCES

FILIUS P, WENIGER J and TEUSCHER T. 1986. Investigation on the performance of *Djallonké* sheep. *Animal Research and Development* 24: 85-97.

JUGESSUR VS, RAMJEE R and RAMNAUTH RK. 1998. The effectiveness of some widely used anthelmintic drugs on endoparasitic nematodes of village goats. *In Proceedings of the Third Annual Meeting of Agricultural Scientists, Réduit, Mauritius, Food and Agricultural Research Council (in press)*.

PETERS KJ, DEICHERT G, DREWES E, FICHTNER G and MOLL S. 1981. Goat production in low income economic units of selected areas in West Malaysia. *Animal Research and Development* 13: 88-113.

STEINBACH J. 1988. Experiences with the evaluation of the production potential of local and imported goat breeds in Northern Tunisia. *Animal Research and Development* 28: 100-114.

THE REPRODUCTIVE PERFORMANCE OF IMPORTED FRIESIAN DAIRY HEIFERS IN MAURITIUS

K Boodhoo* and *AA Boodoo

Agricultural Research and Extension Unit

ABSTRACT

An assessment of the reproductive performance of imported dairy heifers kept by the smallholders and 2 Government farms was made. The milk progesterone radio immunoassay (RIA) was used to study the duration of the post partum ovarian activity and conception rate following artificial insemination or natural service. The smallholder dairy systems studied were in Bambous, Riviere du Rempart and Henrietta and the Government farms in Richelieu and Curepipe. The results show that the overall mean interval from calving to first ovulation was 133 ±70, 129±20 and 158±66 days for the 2 Government farms and the smallholder systems respectively. About 1% of cows resumed ovarian activity within 90 days after calving in all the systems of production. On average, 15.5% of the cows resumed ovarian activity by 120 days. The overall conception rate for the smallholder dairy system was 27% while it was 72% at the Richelieu farm, which uses natural service and only 14% at the other Government farm using artificial insemination. The average calving interval for the 3 systems was 17±3 months The factors, which influence the duration of post partum ovarian activity and conception rate, are discussed. In addition, some practical implications with regard to management practices and future importation programme are highlighted.

Keywords: dairy heifers, dairy cows, smallholders, reproductive performance, conception rate, calving intervals, resumption of ovarian activity, radioimmunoassay, Mauritius.

INTRODUCTION

At present, there are about 12,000 head of cattle in Mauritius out of which smallholders commonly known, as cow keepers own 75%. These are predominantly women and they own on an average one to two head of cattle. On the other hand, there is also a growing group of progressive farmers who own about 10-15 animals. Together, they produce about 95% of the total fresh milk in the country. During the past few years, Government resorted to the importation of dairy heifers from Zimbabwe, South Africa and Australia to satisfy the growing demand from smallholder milk producers for breeding animals. For the farmers to get the maximum benefit from these animals it is essential that they are well managed to achieve an efficient reproductive performance. For example, it would be desirable to target a 12-13 month calving interval since sustained lifetime milk production will be maximised only if reproduction is optimal. However, in view of the numerous complaints received, namely about cows (those from Zimbabwe) not conceiving after artificial insemination (AI) and cows still not showing oestrous signs 3 months after calving, a study was undertaken to document the reproductive performance of the animals imported from Zimbabwe under our local conditions.

The objective was to study the reproductive performance of the imported dairy heifers with reference to their ovarian activity, conception rate and calving interval**.**

MATERIALS AND METHODS

Location

The study was undertaken in 3 different climatic areas in villages and on 2 Government farms. The villages were Bambous (sub humid, <1250 mm of annual rainfall), Riviere du Rempart and Plaines des

Roches (humid, 1500 mm of annual rainfall) and Henrietta and Nouvelle Decouverte (super humid, >2500 mm of annual rainfall) regions. The 2 Government farms are in the sub humid (Richelieu) and super humid (Curepipe) zones. There are two distinct seasons - summer (November-April) and winter (May-October) in Mauritius.

Animals and Feeds

The Smallholder Production Systems

The study was carried out between July and December 94 using 26 imported pregnant Friesian dairy heifers owned by the smallholders. The calving period ranged from August to December 94. They were tethered in a shed in the backyard and fed fodder cut from roadsides or nearby fields. During the sugarcane harvesting season (June to November) the diet consisted mainly of sugarcane tops and some fodder grasses. In addition to the basal diet, which was fed ad libitum, a locally compounded dairy concentrate (cow feed, crude protein of 17% on fresh basis) was also fed at the rate of 5-6 kg per day. All the cows suckled their calves for 3-4 months. The cows were artificially inseminated by the technicians from the Veterinary Services upon request from the farmers.

The Government Farms Production Systems

In the sub humid zone the study was carried out at the Richelieu Livestock Production Unit between March and September 96 using 23 imported pregnant Friesian dairy heifers. The calving period ranged from March to June 96. They were kept in 2 pens and fed mainly Herbe d'Argent (*Ischaemum aristatum)* and Setaria *(Setaria sphacelata*). The cows were naturally mated and the bull remained with the herd of cows for about 90 days

In the super humid zone the study was carried out at Curepipe Livestock Breeding Station between June and December 97. It involved 19 individually tethered heifers in a closed byre. The diet consisted mainly of Setaria grass and the animals were bred by artificial insemination.

On both farms, 6 kg of cow feed were also given together with the basal diet. During the sugarcane harvesting season the diet consisted mainly of sugarcane tops and some fodder grasses. All the calves were separated from their dams within 12 hours of calving.

Data and Milk Sample Collection

20 ml of milk were collected twice weekly as from 20 days after calving for determination of progesterone. Each milk sample was preserved with two sodium azide tablets and stored at 4^{o} C. The whole milk sample was centrifuged at 3000 rpm for 15 minutes within 1 week after collection and the fat removed. The skimmed milk was stored at -20^{o} C until assayed for progesterone.

For the smallholder systems the dates of heat as detected by the farmer, first AI and subsequent AI's were recorded. These data were collated with the progesterone profiles of each cow to determine intervals from calving to resumption of ovarian activity and conception rate.

Reproductive records kept at the 2 Government farms were used to extract data with regard to calving dates, mating time and results of pregnancy diagnosis. Body condition score of the animals was determined using a five-point scale, with a score of 1 being graded as very poor body condition and 5 as being fat.

Determination of Milk Progesterone Levels

The milk samples were assayed for progesterone at the Ruminant Research Laboratory in Richelieu. The progesterone was quantified, in duplicate aliquots, by the solid phase radioimmunoassay supplied by the Joint FAO/IAEA Division of Agriculture Laboratory, Seibersdorf, Austria (Plaizier 1993).

RESULTS

Resumption of Ovarian Activity and Ovarian Cycles

Ovarian activity was identified when the first progesterone rise persisted for two weeks and was followed by a week of basal values. The results of the sequential progesterone determinations for each cow were plotted. The percentage of cows resuming ovarian activity by different periods for the 3 production systems is shown in **Table 1**.

26% of the cows resumed ovarian activity by 90 days at the Richelieu farm. At Curepipe none of the cows resumed ovarian activity within this period of time while it was only 7 % in the smallholder production system. The longest mean interval from calving to first ovulation occurred in the smallholder system (158±66 days). The values for the three systems ranged from 100 to 225 days indicating a very wide variation in the time taken to resume ovarian activity. Thus only few cows resumed ovarian activity within 90 days after calving in all the three production systems. However, all cows showed normal oestrous cycles after resumption of ovarian activity till diagnosed pregnant.

Table 1 % of cows resuming ovarian activity by different periods of time and overall mean interval from calving to first ovulation for the 3 systems of production

Days post calving	Richelieu	Curepipe	Small holder system*
0-90	26 (6)**	0 (0)	7 (2)
91-120	22 (5)	15 (3)	12 (3)
>120	35 (8)	47 (9)	54 (14)
Non cyclic cows	17 (4)	37 (7)	12 (3)
Total Number of cows	23	19	26
Mean interval (days ± sd)	133 ± 70	129 ± 20	158 ± 66

* Cows were sold; data for them are not available. ** The number in brackets indicates the number of cows involved

Conception Rates and Calving Intervals

The conception rates and calving intervals for the three systems are shown in **Table 2.** The first service conception rate and overall conception rate for the smallholders' cows were only 13% and 27% respectively. At the Curepipe farm the corresponding values were 6% and 14% while at Richelieu which uses natural mating, they were 50% and 72% respectively. The values for Richelieu are considered satisfactory while those for the smallholders and Curepipe were very low indeed. The calving interval ranged between 13 and 15 months for the cows at the Richelieu farm while a longer calving interval ranging from 13 to 21 months for the smallholder production systems was observed. The value for Curepipe was as long as that of smallholders.

Table 2 : Summary of the main reproductive parameters of the cows in the three systems

Reproductive parameters	Richelieu (Natural Service)	Curepipe (AI)	Smallholder (AI)
First service conception rate (%)	50	6	13
Overall Conception rate (%)	72	14	27
Interval from calving to first service (days ± sd)*	66 ±7	102 ±19	197 ±104
Average calving interval (months ± sd)	14 ±1	17 ±5	17 ±4

* standard deviation

DISCUSSION

Resumption of Ovarian Activity after calving

The time taken to resume ovarian activity after calving by the imported heifers in the 3 production systems ranged from 100 to 225 days and is considered to be long. In a previous study, Boodhoo et al. (1997) showed that cows, reared by the smallholders, resumed ovarian activity in 86 ± 38 days after calving. Furthermore in a recent trial at Curepipe with local cows ovarian activity resumed within a period of 30-40 days; these cows were reared under similar conditions as the imported cows (unpublished data). It is to be noted that on the 2 Government farms the cows resumed ovarian activity earlier than in the smallholder systems.

In the 2 farms of this study one possible explanation of this long delay in resumption of post partum ovarian activity could be the effect of nutrition. Studies in other tropical countries have indicated a strong interaction between energy reserves in the pre and post calving periods and resumption of ovarian activity after calving (Butler and Smith 1989; Ferguson 1996; Peters 1984). They suggested that inadequate dietary energy intake in the late precalving and early post calving period might delay resumption of ovarian activity. Since in this study it was not possible to gauge the energy status of these cows during both periods, body condition score (BCS) was used as an indicator of how well the animals were fed. A number of studies have reported that cows calving with a BCS in the range of 3-4 are associated with intervals ranging between 30 and 50 days from calving to resumption of ovarian activity (Wright et al 1992; Ramirez et al 1992; Sharpe and King 1981).

In the present study since most of the heifers at the 2 Government farms were in a body condition of 2 soon after calving, it is possible that the feeding regime did not allow them to accumulate sufficient energy reserves to allow them to show ovarian activity earlier. In addition, since these heifers were calving for the first time, inadequate energy reserves would be even more detrimental to reproduction. For it is known that in primiparous cows growth and lactation have a higher priority than reproduction in a situation of low energy reserves (Short and Adams 1988). Interestingly, it appears that the mean time to onset of ovarian activity (133±70 and 129±20 days at Richelieu and Curepipe respectively) coincided with the post peak period of the lactation cycle when the energy demand for lactation has diminished. This could have then allowed the cows to attain an energy status to favour resumption of ovarian activity.

Despite the fact that the animals in the smallholder system calved with a BCS of 3 and maintained it throughout lactation, the interval to resumption of ovarian activity was variable and long (158±66 days). Since the cows suckled the calves and the latter were tied up in the shed near their dams, it is surmised that this may have been important in retarding return to ovarian activity. This argument is supported by recent research, which has clearly demonstrated the importance of the maternal-offspring bond and suckling in its suppressive effect on resumption of ovarian activity (Williams *et al.*, 1996). Hence it is suggested that suckling may have caused a longer delay in resumption of ovarian activity after calving in the smallholder systems than in the 2 Governments farms, albeit a long delay in onset of ovarian activity in the 3 systems.

This long delay in resumption of ovarian activity also explains the numerous justified complaints of the smallholder dairy farmers about their cows not showing any signs of heat 3 months after calving.

Conception Rates

The conception rate of the cows kept by the smallholders was poor (13%). This low conception is believed to be due to several factors such as timing of insemination, semen quality and inseminator technique (Esselmont 1992). This poor conception rate resulted in some cow keepers selling their cows (15%) though they had a normal oestrous cycle pattern (that is they were fertile), as revealed by the progesterone profiles.

At the Richelieu farm the conception rate was higher as the cows were naturally mated. In spite of their BCS of 2 all the cows that resumed ovarian activity (20 out of 23) were diagnosed pregnant after running with the bull. This indicates that despite a late resumption of ovarian activity the cows ovulated normally and conceived. It is therefore felt that if those cows in the smallholder farms had the

opportunity to run with a bull, a better conception rate would have been possible and this would have prevented unwarranted culling of animals.

However, at the Curepipe farm none of the 19 cows conceived except one. This is explained by the fact that all the cows had been given a single injection of prostaglandin - a hormonal treatment -and inseminated 48 hours later at a time when they were not cyclic, as shown by the progesterone profiles. It is known that treatment with prostaglandin is only effective if cows are showing normal oestrous cycles at the time of injection (Odde 1990)

Calving Intervals

This study has shown that the calving interval ranged between 13 and 22 months for the 3 systems of production. However, the long calving interval (an average of 17 months) for the smallholder cows and the farm at Curepipe is a cause for concern. In this study such long calving intervals may have been due to a combinations of 2 main factors - long intervals from calving to resumption of ovarian activity and low conception rate to AI (**Tables 1** and **2**). On the other hand, on the Richelieu farm a shorter calving interval (an average of 14 months) was achieved despite a delay in resumption of ovarian activity. This was possible as the cows were naturally mated, indicating that once the cows were cycling normally conception followed immediately. Such a system of natural mating therefore resulted in a better reproductive performance compared to the other 2 production systems.

Calving interval affects a cow's life time milk production and it is known that for a cow to achieve economic and efficient milk production the calving interval should be between 12 and 13 months (Esselmont 1992; Peters 1996). Thus the long calving intervals of the cows in this study have undoubtedly resulted in a less than optimum milk production.

Practical implications

In light of the above results it is clear that to avoid poor reproductive performance of the imported animals it is imperative that

A greater educational effort is necessary to make the farmer aware of the importance of artificially rearing the calves and to inseminate the cows at an earlier time once the cows start to show signs of heat.

A close monitoring of the reproductive status of the cows is made by RIA of progesterone in milk before any hormonal treatment or sale is envisaged, to prevent culling of fertile animals.
The problems associated with AI are given urgent attention.

CONCLUSION

The data show that late resumption of ovarian activity and poor conception rate were important factors contributing to the low reproductive efficiency of these dairy animals as reflected by their long calving intervals. Such reproductive performances represent a serious limiting factor in the effective use of these animals for increased productivity. Though the results presented for the different groups of cows have been obtained during different periods of calving they have nevertheless shed light and provided some valuable indications of the reproductive performance of the imported heifers.

ACKNOWLEDGEMENTS

We thank the FAO/IAEA for their technical support and provision of the progesterone kits. We are grateful to the cow keepers in the regions of Bambous, Plaine des Roches, Riviere du Rempart, Henrietta and Nouvelle Decouverte for having given us the relevant samples, data and information. The Officers in charge of the 2 farms are thanked for their support in conducting this study.

REFERENCES

BOODHOO K, RANGASAMY M and TOOLSEE P. 1996. A preliminary assessment of the reproductive performance of smallholders' dairy cows in Mauritius. *Revue Agricole et Sucriere de Ile Maurice* Vol 6 No.1.

BOODHOO K, TOOLSEE P, MOONEERAMSING M, RANGASAMY M and BOODOO AA. 1998. An assessment of the reproductive performance of smallholders' dairy cows using the milk progesterone radioimmunoassay technique. *In* Lalouette et al. eds *Proceedings of the Second Annual Meeting of Agricultural Scientists*, Reduit, Mauritius, 12-13 August, 1997.

BUTLER WR and SMITH RD. 1989. Interrelationships between energy balance and post partum reproductive function. *Journal of Dairy Science* 72: 767-787.

ESSELMONT R.J. 1992. Measuring dairy herd fertility. *Veterinary Record* 131: 209-212.

FERGUSON JD. 1996. Diet, production and reproduction in dairy cows *Animal Feed Science Technology* 59 173-184

ODDE KG. 1990. A review of synchronisation of oestrous in post partum cattle. *Journal of Animal Science* 68 817-830.

PETERS AR. 1984. Reproductive activity of the cow in the post partum period. I Factors affecting the length of the post partum a cyclic period. *British Veterinary Journal* 140:74-84

PETERS AR. 1996. Herd management for reproductive efficiency. *Animal reproduction Science* 42:455-464

PLAIZIER JCB. 1993. Validation of the FAO/IAEA RIA kit for the measurement of progesterone in skim milk and blood plasma. *In Proceedings IAEA, TECDOC-708*, IAEA, Vienna.

RAMIREZ LI and BELLOSO ES. 1992. Factors affecting postpartum ovarian activity in primiparous tropical Heifers *Theriogenology* 48 449-460

SHARPE PH and KING GJ. 1981. Post partum ovarian function of dairy cows in a tropical environment. *Journal of Dairy Science*. 64 672-677.

SHORT RE and ADAMS DC. 1988. Nutritional and hormonal interrelationships in beef cattle reproduction Canadian *Journal of Animal Science* 68 29-39.

WILLIAMS GL, GAZAL OS, GUZMAN VEGA GA and STANKO RL. 1996. Mechanisms regulating suckling-mediated anovulation in the cow . A*nimal Reproduction Science* 42 289-297.

WRIGHT IA, RHIND SM, WHYTE TK and SMITH AJ. 1992. Effects of body condition at calving and feeding level after calving on LH profiled and duration anoestrous period in beef cows. A*nimal Production* 55 41-46.

PREWEANING PIGLET MORTALITY IN MAURITIUS

VS Jugessur

Agricultural Research and Extension Unit

ABSTRACT

About 10 to 15% deaths usually occur in piglets from their birth until they are weaned at the age of about 8 weeks from their mothers. Mortality rates exceeding 15% constitute serious overhead expenses in any piggery across the world. The causes of preweaning piglet mortality are varied and may be due to predisposing factors such as bad management, susceptibility to diseases, sow health and extremes of weather. A study carried out from June 1996 to February 1998 on 18 piggeries and in different regions of the country and involving 100 randomly selected sows and their three consecutive litters of piglets has enabled the identification of the factors associated with the causes of piglet mortality and mortality rates due to these. Mortality rates of 17.2%, 19.3% and 24.6% recorded in each cycle were mainly due to overlay, starving, undersized piglets and enteritis.

Keywords: Pigs, weaning; mortality, causes, mortality rates, Mauritius.

INTRODUCTION

Piglets are usually weaned from their mothers at around 45-56 days of age, at which time they can feed themselves on feeds of both animal and plant origin, and have developed the capacity to resist infection from the environment. However, out of the litters of piglets that are born, some 10 to 15% do not survive till weaning time and this mortality rate can be much higher due to various factors. Predisposing factors like overcrowding, bad ventilation, malnutrition, susceptibility to viral and bacterial infection and extremes of weather, and some common factors like enteritis caused by colibacilli, sow health and litter size are major contributing factors of preweaning piglet mortality. Inadequate spatial arrangements and nursing care of piglets cause more than half of the preweaning deaths during the first 36 hours of life and during the following 3 to 4 days (Leman et al 1992).

In Mauritius, preweaning piglet mortality has been a serious problem faced by pig farmers in the smallholder sector, as revealed by a Rapid Rural Appraisal and a Participatory Rural Appraisal that were carried out in 1995 and 1996 respectively, by the Agricultural Research and Extension Unit. These also revealed that besides inflicting heavy economic losses through piglet mortality rates of up to 50% on many farms, the increasing demand for weaners both for breeding and fattening could not be met. A study on preweaning piglet mortality was therefore carried out on selected piggeries in 3 different regions of the island over a period of one and a half years from June 1996 to February 1998 to elucidate the causes associated with such mortalities and to propose remedial actions so as to reduce piglet mortality.

MATERIALS AND METHODS

Eighteen pig farms of varying size and having different management practices were identified from three regions of the country namely, super humid (annual rainfall over 2500mm rain), humid (1500-2500 mm rain) and sub humid region (less than 1500mm rain) as shown in **Table 1**. These farms comprised 3 individual piggeries, 13 cooperative farm units, one prison farm, one government livestock production unit, and one farm run by the Federation of Young Farmers. A random sample of 100 (Large White, Landrace and crosses of these) gestating sows and gilts, mostly of parity 1 and 2 were taken from a total of 313 present on the 18 farms.

Table 1 Selection of farms

Farms	Region			
	Super humid	Humid	Sub humid	Total
Small (Up to 50 heads)	1	2	0	3
Medium (50 - 100 heads)	1	4	3	8
Large (Over 100 heads)	1	3	3	7
Total	3	9	6	18

The farms were visited regularly; case histories of individual sows, boars and litters as well as management practices for the three consecutive reproduction cycles (Litters I, II and III) were recorded on each farm.

EXPERIMENTAL INVESTIGATION

On-farm observations

Management practices related to housing, feeding, reproduction, sanitation and health care were recorded separately for each farm.

Weighing of piglets

Piglets were weighed between day old and 4 days in Litter I only. Birth weights of 180, 481 and 90 piglets from sows of parity 1, 2 and 3 respectively were recorded.

Detection of parasitic infestation

Quantitative analysis of 193 fresh faecal samples from gestating sows and 104 samples from 3 to 4 week old piglets respectively was carried out for endoparasitic helminths and coccidia, by concentration and sedimentation technique using saturated salt solution.

Recording of diseases

Diagnosis of diseases were made on the spot, from case histories of individual sows and of litters as well as from post mortem findings and by the isolation of pathogenic bacteria.

Determination of litter size, preweaning piglet mortality and number of piglets weaned

Mean values were calculated for individual as well as for aggregate farms for 100 first litters, then for second 66 litters and ultimately for 50 third litters from actual observations as well as on information obtained from the farmers.

Identification of the causes of deaths

The factors associated with, as well as the causes of deaths of sows and of piglets from birth until weaning were identified in each cycle, from history, post mortem examination and as stated by farmers.

RESULTS

Litter size, preweaning piglet mortality, stillbirths and weaning rate (**Table 2**). 100 sows and gilts and their litters were studied in the first cycle (Litter I) while in the second cycle following deaths of some sows and farmers culling unproductive ones, the number of sows and their litters (Litter II) were reduced to 66 and finally 50 sows and their litters (Litter III) were left for the third cycle.

Table 2 Litter size, preweaning piglet mortality, stillbirths and piglets weaned in three consecutive reproduction cycles.

	Litter I	Litter II	Litter III
No. of farms	18	13	11
No. of sows & litters	100	66	50
No. of piglets born alive	945	630	512
No. of piglets dead*	163	122	126
Preweaning mortality %*	17.2	19.3	24.6
Stillbirths	41	15	12
No. of piglets alive / litter	9.4 ± 1.4**	9.5 ± 2.2**	10.2 ± 1.4**
No. of piglets weaned / litter	7.8 ± 1.4**	7.7 ± 2.0**	7.7 ± 2.1**

* Does not include stillbirths ** S.E ± - Standard Error

Litter size

The mean litter size for Litter 1 was 9.4 ± 1.4; for Litter II was 9.5 ± 2.2 and for Litter III it was 10.2 ± 1.4, excluding stillbirths.

Preweaning piglet mortality

The mortality rates in Litter 1 ranged from 0-34.2% with a mean of 17.2 %, in Litter II from 0-46.6% with a mean of 19.3 % and in Litter III from 0-80% with a mean of 24.6%. The mean mortality rates for the ultimate 50 sows that gave 3 consecutive litters were 17.6%, 29.1% and 24.6% for Litter I, II and III respectively.

Stillbirths

The incidence of stillbirths was low (4.1%, 2.3% and 2.2 % for Litters I, II and III respectively). The stillbirths were not taken into account while computing the results.

Piglets weaned per litter

A mean of 7.8 ± 1.4 (n=782) piglets was recorded for Litter I, 7.7 ± 2.0 (n=508) for Litter II and 7.7 ± 2.1 (n=386) for Litter III.

Birthweight of piglets

The mean birth weight of piglets at 0 to 4 days of age in Litter I from sows of parity 1, 2 and 3 were 1.23 ± 0.27 kg (n=180); 1.24 ± 0.19 kg. (n = 481) and 1.29 ± 0.26 kg (n = 90) respectively.

Causes of preweaning piglet mortality

The main causes of deaths in all the 3 litters were found to be overlay, starving, undersized piglets, diarrhoea and these represented 27.9%, 26.2%, 18.9% and 15.5% respectively of all the deaths of the three litters combined. The other causes of lesser importance were septicemia (3.6%), anaemia (1.9%), savaging (0.97%), atresia ani (imperforate anus) (0.72%), pneumonia (0.48%) and splay legs (0.48%) (**Table 3**).

Table 3 Causes of preweaning mortality for the three cycles combined

Cause	Number of deaths	Number of deaths autopsied	% Deaths due to each cause
Overlay	115	33	27.9
Starving	108	22	26.2
Born Weak	78	36	18.9
Diarrhoea	64	30	15.5
Septicemia	15	15	3.6
Unknown	12	-	2.9
Anaemia	8	8	1.9
Savaged	4	-	0.97
Atresia Ani	3	3	0.72
Splay legs	2	2	0.48
Pneumonia	2	2	0.48
Total	411	151	100

Percentage deaths of total deaths recorded as well as of total piglets born due to all these causes in each of the three reproduction cycles and in the superhumid, humid and subhumid regions are given in **Tables 4, 5** and **6**.

Table 4 Causes of preweaning mortality in each reproduction cycle Litter I, II & III

Cause of death	Litter I		Litter II		Litter III	
	Number of deaths	% Total deaths (n=163)	Number of deaths	% Total deaths (n=122)	Number of deaths	% Total deaths (n=126)
Overlay	41	25.1	40	32.7	34	26.9
Starving	38	23.3	24	19.6	46	36.5
Born Weak	34	20.8	31	25.4	13	10.3
Diarrhoea	26	15.9	17	13.9	21	16.6
Septicemia	15	9.2	-	-	-	-
Anaemia	-	-	8	6.5	-	-
Savaged	2	1.2	-	-	2	1.5
Atresia ani	2	1.2	-	-	1	0.79
Pneumonia	1	0.61	-	-	1	0.79
Splay legs	-	-	2	1.6	-	-
Unknown	4	2.4	-	-	8	6.3
Total	163	100	122	100	126	100

Parasitic infestations

Presence of helminth parasites and coccidia was detected on 16 farms (88%) in pregnant sows and on five farms (28%) in piglets 3 to 4 weeks of age. Helminth ova of *Ascaris suum, Oesophagostomum dentatum, Trichuris suis, Strongyloides ransomi, Megastrongylus apri, Stephanurus dentatus* and *Coccidia oocysts* of *Eimeria* species were identified.

Table 5 Preweaning mortality of piglets born in each reproduction cycle due to different causes

Causes	Litter I		Litter II		Litter III	
	Number of deaths	% of total born (n=945)	Number of deaths	% of total born (n=630)	Number of deaths	% of total born (n=512)
Overlay	41	4.3	40	6.3	34	6.6
Starving	38	4	24	3.8	46	7.3
Born Weak	34	3.6	31	4.9	13	2.5
Diarrhoea	26	2.7	17	2.7	21	4.1
Septicemia	15	1.6	-		-	
Anaemia	-		8	1.2	-	
Savaged	2	0.2	-		2	0.4
Atresia ani	2	0.2	-		1	0.2
Pneumonia	1	0.1	-		1	0.2
Splay legs	-		2	0.3	-	
Unknown	4	0.4	-		8	1.5
Total	163	17.2	122	19.3	126	24.6

Table 6 Preweaning mortality in different climatic regions

Causes	Super humid		Sub humid		Humid	
	Deaths					
	Number	%	Number	%	Number	%
Overlay	4	66.6	68	30.9	43	23.2
Starving	-	-	70	31.8	38	20.5
Born Weak	1	16.6	24	10.9	53	28.6
Diarrhoea	1	16.6	30	13.6	34	18.3
Septicemia	-	-	7	3.1	8	4.3
Anaemia	-	-	8	3.6	-	-
Savaged	-	-	2	0.9	2	1.0
Atresia ani	-	-	3	1.3	-	-
Pneumonia	-	-	-	-	2	1.0
Splay legs	-	-	2	0.9	-	-
Unknown	-	-	7	3.1	5	2.7
Total	6	100%	220	100%	185	100%

DISCUSSION

Management of farrowing pens

Farrowing crates

Up to 20% of preweaning deaths may be due to overlay in piggeries where farrowing crates are not well designed (Leman et al 1993; Rao et al 1992). Non confinement of sows in farrowing crates or confinement in improperly designed ones resulted in overlay which caused 41 deaths (25.1%) in Litter I, 40 (32.7%) in Litter II and 34 (26.9%) in Litter III (**Table 4**). It was also observed that out of 18 farms, 6 (33.3%) had farrowing crates and on only 3 farms (16.6%) the farrowing crates were well designed. On one of the latter 3 farms which was also the largest (496 head) and had the best designed

farrowing crate, the lowest mortality rates of 7.3%, 7.6% and 7.0% were recorded in the respective litters as compared to the average 17.2%, 19.3% and 24.6% for all the farms in the respective Litters I, II and III. On this farm no death was reported to be caused by overlay thus showing the usefulness of a well-designed farrowing crate.

Sanitation

Well drained floors enabling proper disposal of faeces and urine were found in 9 farms (50%) (two government owned and seven private farms). However, routine disinfection was carried out on only one government farm, where the maternity pen was disinfected before introduction of the sow. Of the 411 total deaths recorded for the three reproduction cycles combined, 15.5% were due to diarrhea and enteritis and this can be associated with poor hygiene which is an enteritis risk factor. It has been reported (Leman et al, 1992) that 5-15% deaths of piglets can be due to viral and bacterial infections, which cause enteritis and death. In the study, E. coli was isolated from 15 (3.6%) deaths due to septicemia.

Creep area and creep feeding

Although creep area was adequate and creep heat was provided on 12 (66.6%) farms, bedding for comfort of piglets was provided on only 6 (33.3%) farms. Creep feed fed to piglets after one week of age enables them to build up immunity since the sow's milk production as well as its lactose content fall after about 2 weeks after farrowing (Leman et al, 1992). It was observed that creep feed was given on 12 (66.6%) farms, but on 9 of these (75%) the piglets had access to the sows ration as well.

Animal-farmer interaction

On 7 farms (38%), farmers were present at the time of parturition and would provide assistance to the sows and piglets if required. Obviously, mortality rate due to overlay could have been reduced if there were more animal-farmer interaction during the first days following farrowing.

Health Care

Iron injection was given to piglets on 17 (95%) farms, but on only 7 (38.8%) farms it was given at the recommended time, that is at 3 days. Although iron injection was not given at 3 days, yet preweaning piglet mortality due to anaemia was only about 2% for the three cycles combined and was therefore not a serious problem. Animals were dewormed regularly during each cycle on 9 (50%) farms and treatment against diarrhoea was given promptly on 8 (44.4%) farms whereas almost all farmers complained of not receiving timely veterinary assistance which contributed to death of piglets suffering from diarrhoea.

Sow factors affecting piglet mortality

Nutrition of gestation sows

On 5 (28.5%) farms concentrates were fed adequately and the amount fed was increased during the last fortnight of gestation. This is essential so as to allow the foetus to accumulate energy reserves (Leman et al 1992). Only swill and garbage were fed to the sows on 2 farms (11.1%), although these feeds were normally given to fatteners. On the latter farms, all the sows under study were sold because of poor condition, after the first cycle. Apart from two Government farms, on the remaining 16 farms very often the ration of pregnant sows included cooked or uncooked swill and very less concentrates as the farmers found it to be more economical to feed swill. The nutrition of gestating sows is considered to be very important as an inadequate supply of milk to piglets can cause a high rate of preweaning deaths due to starvation. One hundred and eight (26.2%) deaths of piglets was due to starving piglets that were unable to get sufficient milk from both agalactic sows and those affected by perihypogalactic syndrome (PHS) (**Table 3**). PHS which was observed in 18 (18%) sows could be associated with nutrition and not to infectious causes, since mastitis was detected on only one affected sow. A few farmers resorted to fostering the piglets from agalactic to other sows but this did not reduce mortality. Nutritional deficiencies could also have been responsible for small, non-viable piglets which were the

cause of 77 (18.9%) of the total deaths for the 3 cycles combined and for a peak of 25.4% in the second cycle.

Hereditary factors

Sow factors also included although to a lesser extent, hereditary factors which must have been associated with deaths of piglets due to atresia ani and to splay legs (Leman et al, 1992), as well as to mismothering and savaging.

Mortality in different climatic regions

From the range of mortality rates recorded in the study and the causes thereof in the super humid, humid and subhumid regions, it was not evident that mortality rates could be directly related to any particular region (**Table 6**).

CONCLUSION

Four main factors namely: feeding of gestating sows, arrangements in farrowing pens, sanitation and control of diarrhoea in piglets were closely associated with a relatively high preweaning piglet mortality rate. The main causes of deaths were identified as overlay, non viable piglets, starving, insufficiency of milk for suckling piglets and enteritis. The preweaning death losses in piglets could be considerably reduced if farmers would improve sow nutrition, provide well-designed farrowing crates, disinfect farrowing pens and attend promptly and efficiently to scouring piglets.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the assistance received from the Division of Veterinary Services, Ministry of Agriculture, Food Technology and Natural Resources; Mr V. Vally, Assistant Research Scientist, Livestock Research Department, AREU; the Commissioner of Prisons; the Manager of Federation Young Farmers and all the farmers who allowed access to their farms and supplied information.

REFERENCES

LEMAN AD, STRAW BE, MENGELING WL, D'ALLAIRE S, TAYLOR DJ. 1992. *Diseases of sw*ine, Iowa State University Press/AMES, IOWA, USA.

RAO AN et al. 1992. Mortality pattern in piglets - a statistical analysis. *Indian Journal of Animal Sci*ence Vol.63 (7).

ERADICATION OF THE ORIENTAL FRUIT FLY, *Bactrocera dorsalis* (HENDEL) FROM MAURITIUS

SI Seewooruthun, S Permalloo, P Sookar, M Alleck, B Gungah, AR Soonnoo* and *H Abdoula

Ministry of Agriculture, Food Technology and Natural Resources

ABSTRACT

The Oriental fruit fly, Bactrocera dorsalis was detected for the first time in Mauritius on 5 June 1996 at Camp Carol, a village situated at about 1.5 km from the only airport. A single female fly was caught in a Mc Phail trap which was part of an island wide trapping network put in place in the context of a national fruit fly control programme.

An eradication campaign was established immediately upon detection of Bactrocera dorsalis, based mainly on Bait Application Technique (BAT) and Male Annihilation Technique (MAT). Other measures were cover spraying of fruit trees, soil drenching under fruit tress and intensive fruit clean up. An ULM aircraft was also used for BAT and MAT in inaccessible areas. BAT consisted of spot sprays of a protein hydrolysate/malathion mixture at 7 to 10 days intervals. Implementation of MAT involved fixation of plywood blocks, impregnated with methyl eugenol (ME) and malathion, at the rate of 10 - 14 blocks per hectare, renewed every three months.

Monitoring for detection consisted of intensive trapping with dry and wet traps and fruit sampling. 367 dry traps lured with ME and 95 Me Phail traps were operated in the eradication area.

Eradication measures were applied over an area of 300 kM2 in the South until June 1998.

Bactrocera dorsalis was trapped from 22 villages over an area of 250 kin^2. A total of 144 flies were caught. The last adult was trapped on 6 May 1997. B. dorsalis was not at any moment detected in any other part of the island. Bactrocera dorsalis emergence was recorded from 3 samples of mango and six of Indian almond. 88 adults Bactrocera dorsalis were reared from these samples. The last emergence was on 12 May 1997 from Indian almond.

Bactrocera dorsalis is officially declared to have been eradicated flom Mauritius as from 01 July 1999. Measures for the prevention and detection of future introductions of this or other exotic fruit flies continue.

UREA MOLASSES MULTINUTRIENT BLOCKS (UMMB) AS A FEED SUPPLEMENT FOR RUMINANTS

H Bheekhee

Agricultural Research and Extension Unit

ABSTRACT

Molasses is a major by-product of the sugar industry in Mauritius and is still under-utilised for livestock production because of legislation and handling problems. A combination of urea, molasses and other feed ingredients can be used to produce urea-molasses multinutrient blocks (UMMB) that can be fed to livestock as a supplement. The main objective of UMMB supplementation is to provide a constant source of degradable nitrogen throughout the day, to promote growth of rumen microbes in ruminants fed poor quality forage. Studies with cattle, goats and sheep elsewhere indicate that supplementation with UMMB resulted in increased milk yield and growth rate when no other form of supplementation was given. In Mauritius, studies have shown that UMMB can be utilised as a supplement in the smallholder dairy cattle production system as well as in the deer production sector.

INTRODUCTION

Ruminant livestock production is almost entirely dependent on feeds consisting of fodder and crop residues. These feeds are often of poor quality, usually deficient in protein and minerals. To improve production, the efficiency of utilisation of the available feed resources can be optimised by the use of supplements that provide the deficient nutrients. Generally for such purpose, concentrates such as cottonseed cake and cowfeed which are high in protein are used as supplements. The purpose of supplements is to provide nutrients that are deficient in the basal diet and nutrients needed for production. Some of these supplements can sometimes be manufactured using locally available ingredients and agro-industrial by-products.

Molasses which is a major by-product of the sugar industry in Mauritius, is a good, palatable and cheap source of energy for ruminants. Use of liquid molasses by small farmers, however, is very limited due to problems related to transport, storage and legislation. One strategy to get over this obstacle and increase the use of molasses is through the manufacture of urea-molasses multinutrient blocks (UMMB). The technique is to mix the different ingredients in a container and to pour the mixture in moulds to solidify into blocks. Major advantages of using the blocks are their convenience in terms of packaging, storage, transport and ease of feeding. Blocks can thus provide an avenue to maximize the use of locally available feed materials such as molasses and bran for feeding ruminants, thereby reducing the use of high cost concentrate feeds. This strategy of producing UMMB has been proposed by the International Atomic Energy Agency (IAEA) in order to develop affordable and sustainable supplementation packages for improving the productivity of smallholder farms.

DEVELOPMENT OF UMMB

Investigations at AREU have led to the formulation of UMMB using locally available ingredients namely sugarcane molasses, urea, common salt and wheat bran. Other ingredients such as minerals, vitamins and a source of good quality protein like cottonseed cake or soya bean meal are imported but readily available on the local market. Cement is used as a binding agent. Studies conducted in Canada and USA on the utilisation of cement and its by-products as minerals for animals did not reveal any negative effect when fed up to a maximum of 3% of the total daily dry matter intake (Aarts et al, 1990).

The proportion of ingredients used in the manufacture of two sets of UMMB, A and B, using two different amounts of molasses is shown in **Table 1**. The level of cement as a binding agent is adjusted to obtain blocks of good texture and hardness that regulate intake by the animals. To obtain a good setting, cement needs a minimal quantity of water, just enough to make a paste for proper mixing.

Table 1 Proportion of ingredients used in the manufacture of UMMB at Curepipe Livestock Research Station

Ingredient	% by weight (fresh basis)	
	A	B
Molasses (>80° Brix)	40	45
Urea	10	8
Mineral Mixture	5	3
Common Salt	3	2
Cottonseed Cake	5	6
Cement	17	12
Wheat Bran	20	24

Ratio water:cement is 2:5

All ingredients should be weighed accurately before mixing. Mixing can be done either manually for small quantities, or mechanically using a concrete mixer, or a horizontal paddle mixer for large quantities. The sequence in which the ingredients are mixed is very important. Urea is first added to the molasses and thoroughly mixed. All lumps should be broken down to ensure proper mixing and to avoid toxicity problems when fed to animals. Mineral mixture, cottonseed cake and half of the amount of salt are then added, while mixing continuously. The remaining half of the salt is mixed with cement and water to make a paste, which is then added to the molasses mixture and thoroughly stirred to obtain a consistent paste. Wheat bran is added last, little at a time and thoroughly mixed until the product is homogeneous. This product is then ready to be placed in moulds.

MOULDING AND DRYING

Moulds can be made of wood, plastic, iron or carton boxes, which may be of any shape and size. A plastic sheet placed in the mould or an oil film prevents the block from sticking to the wall and allows easy removal from the mould. Once the mixture is placed in the mould, it should be left in a well-ventilated room to set. The mixture takes about 48 hours to set, after which the blocks are ready to be utilised. For cattle, 10-kg blocks seem to be convenient. Blocks wrapped in a plastic sheet or left in carton boxes can be stored in a dry place for several months. Table 2 indicates the chemical composition of the two sets of UMMB, A and B.

Table 2 Chemical Composition of UMMB (% fresh matter basis)

	A	B
Crude protein	27.5	30.5
Crude fibre	2.2	2.1
Fats	1.4	0.3
Calcium (as Ca)	5.5	4.8
Phosphorus (as P_2O_5)	1.4	2.1
Ash (other than Ca and P_2O_5)	17.6	16.9
Carbohydrates, sugars, etc.	22.1	26.7

The dry matter (DM) content of block A is 77.7% and that of block B is 83.2%. The mean calculated metabolizable energy (ME) of the supplements A and B are 10.9 and 11.0 MJ/kg DM respectively.

FEEDING OF UMMB

UMMB must only be fed to post-weaning, growing or adult ruminants and never to monogastric species or to pre-ruminant calves, kid goats, lambs and deer fawns because of urea toxicity problems. Since blocks are supplements they should always be used with a minimum quantity of roughage. Blocks are introduced gradually in the diet of ruminants during a transition period of about 2 weeks to enable the animals to adapt to the new supplement. Afterwards, blocks are offered to animals without any interruption. Blocks being palatable, are licked by animals according to their requirement, thereby regulating the intake of urea so as to ensure its efficient utilisation, without any risk of toxicity. The targeted daily intake by adult animals should be 700 g/head for cattle, 150 g/head for deer and 100 g/head for goats and sheep.

BENEFITS

Consumption of UMMB depends on the type of fodder or roughage and concentrates in the diet as well as on the physiological state of the animal. The positive effect of UMMB intake on overall performance of an animal will be more pronounced on a low plane of nutrition, that is, a crop-residue or straw-based diet. According to Hendratno (1997), there is a significant improvement in body condition and reproductive performance as well as an overall increase in milk yield. Also, higher amounts of molasses may be utilised not only as a feed component but also as a vehicle for urea, minerals and rumen non-degradable protein to cater for nutritional deficiencies.

MEDICATED BLOCKS

Another potential for UMMB supplementation that can be exploited is through the use of medicated blocks, for the control of pests and diseases. Animal species that can benefit from medicated blocks include deer, goats, sheep and young calves. In the deer sector, both the normal and the medicated UMMB can be used. These can prove to be highly advantageous especially in the extensive system of deer production where there is very little control over the animals.

REFERENCES

AARTS G, SANSOUCY R and LEVIEUX GP. 1990. *Guidelines for the manufacture and utilisation of molasses-urea blocks.* Animal Production and Health Division. FAO. Rome, Italy.

HENDRATNO C. 1997. Development and utilisation of UMMB as a feed supplement for ruminants. Paper presented at the First Regional Training Workshop (AFRA) on *"Guidelines for developing supplementation packages*". Morocco. March 1997.

THE EFFECT OF ADMINISTRATION OF PROSTAGLANDIN IN DAIRY ANIMALS ON PREGNANCY RATE

K Boodhoo, P Toolsee* and *AA Boodoo

Agricultural Research and Extension Unit

INTRODUCTION

One of the ways to synchronise the bovine oestrous cycle or induce heat in dairy cows is to inject prostaglandin (PGF2a). It shortens the oestrous cycle and allows the cow to show heat during a restricted time period. PGF2a is most effective if the cows are cycling normally (Odde 1990). In Mauritius, PGF2a is currently being used to induce or synchronise heat in the smallholder dairy cows which fail to conceive after 3-4 inseminations. However, the response to its use is not documented. Therefore, this study was undertaken to gather data on the responses following injection of PGF2a and insemination. The objective of this paper is to compare the pregnancy rates (PR) of synchronised and unsynchronised animals .

MATERIALS AND METHODS

Data for 38 dairy Friesian heifers that were synchronised for heat were extracted from the reproductive records book at Richelieu Livestock Production Unit.(Farm A). The regime of synchronisation was as follows : each heifer was injected with 2 doses of PGF2a at 11 days apart. Inseminations were performed at 48 and 72 hours after the second injection. During the same period another group of heifers (n=68) reaching sexual maturity at weights of 300 kg was naturally mated by allowing the bull to run with them. They were housed in two different pens. Pregnancy diagnosis by rectal palpation was performed 3 months after service /insemination in both groups.

At Curepipe Livestock Breeding Station (Farm B) data were extracted for 83 dairy cows that had been injected with prostaglandins. The regime was a single injection followed by insemination 48 hours later. The animals were individually tethered in a closed byre. The animals were bred by bull or artifcial insemination after injection. At both farms, dates of prostaglandin injection, dates of service and pregnancy test results were recorded. These were used to compute the pregnancy rates (number of pregnant animals over total number tested).

RESULTS

The response of the heifers, at farm A, following injections of PGF2a is summarised in Table 1. The data indicate that the response to PGF2a was poor as evidenced by the low pregnancy rate (39.5%) in contrast to the high pregnancy rate (92%) of the unsynchronised naturally mated heifers.

Table 1 Pregnancy rates of animals under the two regimes of breeding at Farm A

	No of animals	No. regnant	Pregnancy rate(%)
Untreated (natural service)	68	60	92
Treated(Insemination)	38	15	39.5

Table 2 shows the fertility results for cows at Farm B. It indicates that the response to PGF2a was poor as evidenced by the low pregnancy rate (less than 25%) for both groups of cows The pregnancy rate (59%) of the unsynchronised naturally mated dairy cows. is also considered to be low.

Table 2 Pregnancy rates of animals under the two regimes of breeding at Farm B

	No of animals	No. pregnant	Pregnancy rate(%)
Untreated (Natural Service)	44	26	59
Treated (Insemination)	41	20	19
Treated (Natural Service)	42	16	24

DISCUSSION

One of the factors that could have contributed to such variability in reponse to the hormonal treatmnet is the stage of the oestrous cycle at which injection of PGF2a was made. It has been shown that if injections of prostaglandins is made at a point which is too early (e.g., at 0-6 days) or too late (e.g., at 18-21 days) of the oestorus cycle, cows may show heat outside the usual period of 48 and 72 hours for insemination (Watts and Fuquay, 1985). It is therefore surmised that many animals were not on heat at the time of insemination after treatment and this has led to the low pregnancy rates. There is increasing evidence in the literature that inseminations at detected heat or natural mating for a restricted period following synchronisation with PGF2a gives better result than inseminations at fixed time (Voh et al., 1987, Odde, 1990), for it allows to detect those cows showing heat outside the fixed time of insemination. A second factor which could have influenced the pregnancy rate is the degree of anoestrous in the heifers at Richelieu. The possibility that these heifers were anoestrous is small as 92% of the second group of heifers became pregnant during nautural mating, In this study it has therefore not been possible to know the exact casual factor(s) for such low pregnancy rates. The conception rate (59%) registered at farm B for untreated cows is low. The reason for this low fertility are not clear. It is possible that the heat detection accuracy, timing of service and other factors could have influenced the conception rates.

CONCLUSION

Though it would be too premature to extrapolate from these data on the effcetiveness of the use of PGF2a in the smallholder's dairy cows, the above data tend to show that the current practice of PGF2a injections may have to be reviewed. Further investigations are ongoing to gain more insight into the use of PGF2a in the smallholders' dairy system.

ACKNOWLEDGEMENTS

The Officers in charge of the stations are thanked for placing at our disposal the necessary records for extraction of the relevant data.

REFERENCES

ODDE KG. 1990. A review of synchronisation of oestrous in postpartum cattle. *Journal of Animal Science* 68 817-830.

VOH AA, BUVVANENDRAN V and OYEDIPE EO. 1987. Artificial insemination of indigenous nigerian zebu cattle follwing synchronisation of oestrous with prostaglandin : I Preliminary fertility trial. *British Journal Of Veterinary Journal* 143 136-142

WATTS TL and FUQUAY JW. 1985. Response and fertility of dairy heifers following injection with prostaglandin during early, middle and late oestrous. *Theriogeology* 23 655-667.

ARTIFICIAL FEED TRIAL ON SEA BREAM *Rhabdosargus sarba*

Hans Bhudoye* and *Norihisa Ishibashi

Albion Fisheries Research Centre

ABSTRACT

Rhabdosargus sarba is a commercially viable potential aquaculture species. The nutritional performance and success of an artificial diet (tilapia pellets enriched with fish oil) for farmed sea bream versus the traditional factory red snapper pellets has been investigated. This paper attempts to provide some basic guidelines for the formulation of the artificial feed conducive to higher growth rate necessary to compensate the price factor.

EFFECT OF FISH OIL INCORPORATED DIET ON GROWTH OF SEA BREAM *Rhabdosargus sarba*

Hans Bhudoye* and *Norihisa Ishibashi

Albion Fisheries Research Centre

ABSTRACT

The effect of fish oil incorporated with locally available tilapia pellet on growth of the sea bream Rhabdosargus sarba was studied. The fish fed on tilapia pellets with 2 % fish oil grew 1.22 times faster than that fed on normal tilapia pellets for the same rearing period. The average daily growth rate and mean daily weight gain of the fish fed with fish oil incorporated diet were 3.3 % and 0.73 g respectively , whereas fish fed on simple tilapia pellet were 2.6 % and 0.58 g respectively.

Author and Subject Index AMAS 1999