CARIBBEAN FOOD CROPS SOCIETY

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ST. THOMAS, U.S.V.I.

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ST. THOMAS, U.S.V.I.

"Caribbean Economic Stabilization
Through Agricultural Development Strategies"

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FOREWORD

From July 30th to August 5th the 30th Annual Caribbean Food Crops Society (CFCS) convention was held in St. Thomas, U.S. Virgin Islands. This six-day seminar brought together some of the best minds in the area of tropical food production. As with all intellectual gatherings, colleagues profited from each other's research.

These Proceedings of the 30th Annual CFCS Convention highlight the current state of technology and concepts of tropical agriculture, particularly those aspects that pertain to the Caribbean Basin Area.

When a new idea is created or an old one improved upon, it ought to be properly disseminated so that current and future generations may benefit from this knowledge. This is particularly true when these imaginative ideas relate to a developing area such as the Caribbean. Over 60 technical and innovative papers are presented in this document. We will disseminate this document to all interested organizations in the region and hope that the work of our colleagues will truly benefit the people of the Caribbean.

Our staff took much time and effort in producing this document that we all hope will serve a wide range of students, teachers and scientists. I give special thanks to Mrs. Clarice C. Clarke and Dr. Manuel Palada who worked steadfastly in putting this document together.

Kwame Garcia
President - CFCS
Associate Director
Cooperative Extension Service
University of the Virgin Islands

VOTE OF THANKS

Delivered by Miguel Lugo-López
Vice Chairman, Board of Directors, CFCS
August 4, 1994

Thank you, Mr. Master of Ceremonies. Mr. Chairman, ladies and gentlemen. It is indeed a real pleasure and my privilege to extend a Vote of Thanks, on behalf of the directors and members of the Caribbean Food Crops Society (CFCS) and of all other participants in our 30th Annual Meeting, to those who have made, in one way or another, this meeting a reality and a memorable occasion. We always enjoy going back to our roots. The roots of the CFCS are right here in the Virgin Islands where we held our inaugural meeting in 1963. St. Croix was the site of that historical meeting. We returned as a group to St. Croix in 1984, when we became of age, to celebrate our 20th Annual Meeting.

Now, in 1994, we have come back to the Virgin Islands, this time to St. Thomas, to celebrate our 30th Annual Meeting. We long dreamed of coming to St. Thomas and enjoying the hospitality of its people and its beauty. However, we traveled to St. Croix yesterday to get the true feeling of the land where our founding fathers first gathered and to pay tribute to their memory, to their insight, to their vision.

I believe that the CFCS has lived up to what those pioneers envisioned back in 1963. The CFCS is perhaps the only organization of its kind that has outlived all expectations in the region. I am proud, as many of you are, to say that it has become the great, legitimized organization of scientific and technological agriculture in the Caribbean. We have been approached throughout the years by larger U.S. professional organizations and by smaller Central American and Caribbean groups for a merger, but we have withstood those temptations and continued as an independent organization for the past 31 years. I think we can develop effective linkages with others but we can contribute more effectively as we gain strength through our own efforts, to help forge the future of this region.

With this background let us go back to our assignment. A pleasant assignment I should say: to convey our recognition to those who made possible and more pleasant our stay in the Virgin Islands.

Thanks to our distinguished friend Dr. Orville Kean, President of the University of the Virgin Islands, for honoring us with his presence at the Opening Session and for co-sponsoring this event.

Thanks to Dr. Edward M. Wilson, Deputy Administrator of the USDA Cooperative State Research Service, for that excellent and timely keynote address. Dr. Wilson: Please convey our greetings to CSRS Administrator, Dr. John Patrick Jordan.

Thanks are due to Dr. Darshan S. Padda, Vice President of the University of the Virgin Islands, Research and Land-Grant Affairs. As Chairman of the Board of Directors and Chief Executive Officer of the CFCS, his participation at this banquet and throughout the week is deeply appreciated. We praise his unfailing faith and his unexcelled leadership. Under his guidance the CFCS has grown from a small professional society to a highly respected regional organization.

Thanks are also due to Senator Osbert Potter, Chairman of the Economic Development, Agriculture and Consumer Affairs Committee of the Senate of the Virgin Islands for his strong and continuous support. Special thanks to Mr. Eric Dawson, Commissioner, Virgin Islands Department of Economic Development and Agriculture, for co-sponsoring this 30th Annual Meeting of the CFCS with the University of the Virgin Islands and CFCS Local Chapter.

We must give special recognition to Mr. Kwame Garcia, Associate Director, UVI Cooperative Extension Service and President of the CFCS, for his untiring efforts in organizing and conducting an excellent program this week. Thanks to the members of the local CFCS Chapter who helped Mr. Garcia in this challenging and difficult task. I wish I could recognize publicly each of those who

served so willingly and graciously on the Organizing Committee. This will not be possible but as a token of appreciation to all I will just mention one person who symbolically can represent them. I refer to the Chairman of the Organizing Committee, Dr. Louis Petersen.

We have been overwhelmed with the kindness and attentions of the CFCS local group. We are truly grateful. One item I do not want to omit is the cultural event held Tuesday evening which we all enjoyed. It was great. We all enjoyed it. The food was delicious; the drinks, plentiful; the atmosphere, charming; the music lively and provoking.

Thank you.

AGRICULTURAL DIVERSIFICATION IN SMALL ISLAND STATES: THE MARKETING DILEMMA

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ABSTRACT

Agricultural diversification has been promulgated by planners to allow the farmer to spread his risk and to increase the foreign exchange earnings of the country. But it has become evident that the mere addition of other crops will not allow either of these two objectives to be met due to the decline in that sector. The decline is because some of the crops have attained their maximum growth. Profits to be derived is dwindling with a resultant reduction in the production base and, coupled with low productivity, the income to be derived is even lower. Both traditional and nontraditional export crops are similarly affected. Whereas some of the new crops are still in their growth phase, there is a narrow production base and limited market access. The paper seeks to analyze the diversification thrust in Dominica and offers alternatives for a successful program.

INTRODUCTION

Agricultural diversification has been promulgated by planners to allow the farmer to spread his risk and to increase the foreign exchange earnings of the country. But it has become evident that the mere addition of other crops will not allow either of these two objectives to be met due to the general decline in that sector. The decline is due to the fact that some of the crops have attained their maximum growth. Profits to be derived are dwindling with a resultant reduction in the production base and where coupled with low productivity the income to be derived is even lower. Both traditional and non-traditional export crops are similarly affected. Whereas some of the new crops are still in their growth phase there is a narrow production base and limited market access. The paper seeks to analyze the diversification thrust in Dominica and offers alternatives for a successful program.

Dominica is a small English speaking island situated between the French Overseas Departments (FODs) of Martinique and Guadeloupe. The island measures about 753 sq kilometers or 300 sq miles and is very mountainous with the highest peak being 4774 ft. There is a sharp difference in rainfall between the Windward and Leeward coasts. Rainfall ranges from 100 mm or 5 inches on the dry Leeward coast to 8,000 mm or 400 inches per year on the highest peak. Only 30% of the total land area is suitable for agriculture. In the early 1950s large estates were predominant however, by the 1970s new land development schemes saw the division of these estates into small holdings ranging from 1/2 acre to 5 acres. In addition, lands were moved from agriculture into housing development schemes to accommodate the expanding population (Table I).

The economy of Dominica is heavily dependent on the agricultural sector which accounts for approximately 24% of Gross domestic Product annually (Table II) . Banana production is the major activity and accounts for over 90% of agricultural production. The main export market is still the traditional market of the United Kingdom with one major buyer- Geest Industries PLC. Apart from being a price taker in that marketplace there has been little or no control over the disposal of the commodity. It is only recently (last twelve months) that there has been some earnest effort to take more control of the industry.[1]

BACKGROUND

Over the past ten years development strategies for Dominica have placed greater emphasis on

agricultural diversification. The original concept was to diversify away from bananas. However, recognizing the resources employed in this sector and the contribution it makes to economic growth, the thrust of the diversification was shifted to "diversification within bananas" with marginal banana farmers being persuaded to produce other non-traditional export crops. The major objectives of agricultural diversification in Dominica were to:

* Increase food self sufficiency
* Increase food security
* Improve utilization of resources
* Generate employment
* Increase foreign exchange earnings

These objectives were pursued at a national, subregional and regional level. Specific projects were undertaken to realize these objectives however the projects met with varying degrees of success. In some cases adequate resources particularly manpower, were not available. Also difficulties were encountered in transfer of technology. There were conflicts within the whole thrust of the diversification program itself. Increased foreign exchange through exports, conflicted with efforts to realize self sufficiency and food security, which are basically geared towards the domestic market. There are also conflicts between the objectives of improved utilization of resources and employment generation.

The agricultural sector has remained largely underdeveloped with many unsuccessful attempts at establishing sound agro-processing enterprises. Over the years the country has shifted from one main crop to another- sugar, coffee, cocoa, limes, grapefruit, coconut and now bananas. Large scale agricultural production began with the growing of sugar cane which was processed into sugar, rum and molasses. Resources were then shifted into coffee and cocoa with only preliminary processing to prepare the commodities for shipment to the overseas markets where they were further processed. There has also been production of bay leaves which have been processed into bay oil and bay rum- but with the majority of the product being shipped out as a first stage processed product. More recently, the country became involved in the processing of coconut into coconut oil, soap and animal feed.

There has also been the production of limes which were processed into lime juice and lime oil. After difficulties in that sector, grapefruits were also processed into juice concentrate utilizing the lime processing equipment. A serious downturn in the market forced the closure of the factory, producing the citrus concentrates and oils. The latest crop for processing has been aloes which lasted for a period of seven years from the introduction of the crop to the setting up of the factory, for processing and its subsequent closure. Other products being processed currently but on a smaller scale are guava, passion fruit, coffee, tea and hot pepper.

Small ex-colonial territories like Dominica face an uphill battle in their pursuit of agricultural diversification. This dilemma is as a result of a number of inherent structural factors as well as factors external to the sector. Some of these factors are:

(i) As a result of the colonial experience the agricultural sector was directly related to the mother country not only in terms of ownership of the land but also in terms of the marketing arrangements which were closely linked with special companies in the UK. The ancillary services were also owned by the same companies or related ones;

(ii) The economy is dependent on external resources for funding and technical assistance;

(iii) There has been a lack of understanding of the role of the agricultural sector in bringing about full economic independence;

(iv) The training and orientation of the managers in the key economic sectors has been white collar oriented/very academic and non-entrepreneurial;

(v) The services sector in the country has been largely underdeveloped;

(vi) The small size of the domestic market dictates that in order to achieve economies of scale, production must be geared almost entirely to export trade. The small size also poses limitations in terms of development of the necessary ancillary services. No other crop could sustain a viable support services industry. The distortion in the development process of the country resulted in the services meager as they were, to be centered entirely around the main crop, to the exclusion of almost every other one. This distortion has serious repercussions on a small island state. Being small is only part of the problem but to have a distorted economic base, exacerbates the situation, in terms of overall competitiveness:

The limited size of the domestic market(and here even if we include regional to mean domestic) also makes it difficult to attract the type and size of investment required to drive the economy. Services may be present but they are generally inefficient and costly. The Banana Industry has not expanded forward into a key service like transportation(although it has been said that the farmers of the Windward Islands have paid many times over for the initial investment made by the major provider of transportation to the United Kingdom- Geests Industries);

(vii) The production in the agricultural sector is dominated by a large number of small farmers who are generally inefficient. Servicing these farmers is costly and the view has been expressed that the cost outweighs the benefits to be derived.

These factors have prevented us from being market driven and have impacted directly on our competitiveness. Given the very dynamic and very competitive market place, the challenge for a small island like Dominica is, to be as flexible as possible, in order to survive and to generate surpluses.

CONSTRAINTS TO AGRICULTURAL DIVERSIFICATION

As producers of primary agricultural commodities there has been a failure to recognize the various stages in the growth/product life cycle. Hence, there has been a failure to plan for the maturity and decline stages of the product. Even where the country had been the lead supplier e.g. limes, very little thought was given to the possibility that limes might have been replaced by another product. The experience with bay oil and vanilla is similar as the demand for synthetic products became greater.

The assumption has been made that the consumer will always want a particular product. Because of a lack of marketing drive, as well as an appreciation of market forces and variables, those in control have kept their eyes on their product and not on the needs and wants of the market. In terms of fruits and vegetables the market wants variety, good taste, good eating quality, long shelf life, easy access, wholesomeness and generally value for money.

Today with the globalization of the marketplace, consumers are exposed to a wide range of products. What was considered to be very exotic and capable of attracting a premium price, has rapidly attained its maximum in terms of profit returns. In other cases, because of the availability of a wide range of products, consumers are simply not willing to pay a very high price for any one product. In addition, given the perishable nature of the product, there is a limit to the length of time that the product can be kept, to work the market. Even in cases where large sums of money

have been invested, to store these products in cool chains, one wonders whether they will ever cover their costs. The cost of marketing products, is ever increasing with the result that margins are being squeezed. The ratio of marketing cost to production cost has now shifted from 2:8 to 8:2. Without investments in the downstream activities, there is little profit to be generated, by simply selling the fresh product.

The globalisation of the market place is also taking place in the Caribbean. The services and infrastructural support are not geared towards facilitating interisland trade but rather international trade. The regional Hotel sector is geared towards central purchasing out of Miami and other international ports. The cruise ship sector which recently has been growing, is also geared towards central purchasing. Dominica is making a valiant effort to penetrate these markets in spite of the difficulties. Even the supermarkets are tending towards purchasing mixed container loads from Miami.

The real challenge therefore is the ability to market the products that we may be able to produce. The history of marketing arrangements in Dominica has emanated from colonial ties. These ties have also impacted on the development of services in the society. Agricultural marketing as indeed import and export trade, have always been related to the mother country. The key services have been linked from one time or another to the main crop.

Another marketing dilemma which has impacted upon the agricultural sector, is the negative campaign which has been waged against crops like coconuts, by industries in the United States. During the period 1970-1980, Dominica embarked upon a major coconut rehabilitation and expansion program. The international market place waged a war against coconut oil indicating that the product was high in cholesterol and was therefore bad for one's health. Similar campaigns have been waged against products such as coffee during periods of high world market prices. It is obvious that the strong agricultural lobbies in first world countries like the USA, are factors which must be considered in developing our marketing strategies. The cost implication of waging a counter campaign is significant for a small country like Dominica.

Apart from the marketing arrangements all the critical services have been skewed towards the exporting of the main crop. Education has been oriented towards white collar jobs and not to the development of an entrepreneurial culture. At the university level ,the research undertaken has not been related to the socioeconomic needs of the society. The education system which was modelled on the British system has allowed for academic freedom without realizing that the needs of industry should be critical in directing research. In most agricultural regions in the first world, research is directly related to the needs of the sector. Industry supports research through grants and scholarship programs. Regional Universities have only recently begun to respond to the needs being expressed by the agricultural sector in countries such as Dominica.

Governments in the Caribbean region have also pursued policies which have had a negative impact on the diversification efforts - protectionism in the manufacturing sector and import substitution policies of the past have resulted in high local cost of services and goods critical to the production sector, with the result that Dominica has not been very price competitive. Because of the limited resources available for developmental programs, scarce resources are spread out much too thinly, to have any meaningful impact.

The tendency, to look externally for solutions, have allowed us to adopt a number of technical assistance programs from the French, English, Canadians, Americans and Taiwanese. Funding has been received for the development of crops without commensurate funds for marketing of the products. It was assumed that whereas assistance could be given to farmers for producing the crops, a magical private sector would deal with all the marketing functions (Tables III and IV). Decision making for the crops to be developed was based on the availability of funds from external funding agencies rather than at the enterprise level on sound business principles. Scarce human resources are stretched across the various funding agencies in counterparting staff. Much time is spent reporting in various formats and styles, required by each agency. Years are spent preparing projects, with various teams of experts reviewing information again and again. The review of the

information is not usually based on strong business principles.

There has also been a lack of coordination between the three critical elements of the agricultural sector i.e. production, marketing and research. No coordinated system has been developed to ensure that profits generated are reinvested in the sector. The lack of coordination is evident by the absence of investment in research and development of agricultural products by domestic companies and the noninvolvement of most agro-processing firms in production.

The assumption that the agricultural sector could be all things to all persons and could exist in a vacuum has been prevalent. It was not recognized, that the sector existed within the economic structure of the country and as such economic policies can either enhance or hinder its performance.

THE WAY FORWARD

There are a number of factors which impinge on agriculture diversification in Dominica. Some of these factors affect the process at the level of the producers of the commodity and others at the level of the distributor and/or processor of the commodity. At the level of production, the diversification program is affected by:

(i) the choice of crops;
(ii) land availability;
(iii) level of technology;
(iv) land suitability;
(v) farmer commitment and attitude towards risk;
(vii) support measures in production, marketing and research

At the production level the crops being pursued were mostly mature ones. More recently new crops such as spices and exotic fruits were added to the list, but the quantities grown, were not sufficient to create an impact on the market place. The technology even though available, is not always applied or can be very costly on such a small scale. The land available to the farmers, who were interested in growing the new crops, were not always the best, and on the other hand the size of the parcels of land, prevented any meaningful production volume. Directly related to size of land parcels, is the level of risk taken by the farmers. Because the level of commitment associated with any one crop is so small, the farmers can go in and out of the crop without incurring significant losses. This attitude creates tremendous problems for persons and agencies attempting to organize these crops for marketing.

As indicated earlier, the services critical to the development of the other crops are not present. The key services, even though available for bananas, do not belong to the local industry, and cannot be commandeered towards the support for the other crops. The most important elements being the infrastructural support and marketing support. Although the research function is controlled by the banana industry, the services have not been made available to other crops. The economies of scale which should obtain to make Dominican products more price competitive cannot be achieved.

Public-sector intervention in the agricultural sector takes place in the three critical areas referred to above-research, marketing and production. At the national level the Ministry of Agriculture is responsible, for the education of farmers and transfer of technology. The Dominica Export Import Agency (DEXIA) is responsible for the promotion of exports and facilitating the movement of crops through the private sector. At a regional level the Caribbean Agricultural Research and Development Institute (CARDI) is responsible for research through country offices. The Agricultural Diversification & Coordination Unit of the Organization of Eastern Caribbean States (OECS) is responsible for critical support both to the production and marketing modules.

Is agricultural diversification sustainable in small island states? A USA based consumer

group has stated that "trade and a sustainable environment are incompatible."[2] Given current global trends in environment protection and management, and the threat of been ostracized by the world community if one does not adhere to the principles of sustainable development, how realistic it is for small island states to pursue an agriculturally driven economy - monoculture or diversified base? The international market place is demanding adherence to international standards, in quality of products, labelling and packaging. Compliance to these standards and other market entry requirements have to be certified by an internationally recognized body. The responsibility, for ensuring that the products meet market requirements is entirely that of the exporting country. In the food sector these requirements can be very onerous and costly. (One recalls the incident of the contaminated grapes from Chile).

There are a number of critical questions which must be examined before a definitive statement can be made on the outputs of an agricultural diversification program in a small island state like Dominica. Given the critical economic climate prevailing at this time, can the right type of investment be attracted? Is it possible? Are the resources available to create the enabling environment, that is needed? Is it economically viable to produce crops for agro-processing? Can markets, for which there are preferential access, be penetrated successfully, without the key services such as marketing and transportation?. What is our real competitive advantage? Are there any? For which crops is there a competitive advantage? Which markets are to be targeted? Is the present structure and function of government compatible with economic development and finally are island states economically viable?

It is quite clear that any strategy to achieve the objectives of agricultural diversification must be a comprehensive one. Development programs for any crop must include all the necessary linkages, in relation to production, marketing, research and development and the critical support services e.g. transportation.

The banana industry, should have diversified both in terms of the expansion of the product range through agro-processing and by expanding downstream into the services associated with the product, for example marketing, transportation and packaging. The diversification program has been emphasizing the non-sole-dependence on bananas without attempting to examine structure and function of the banana program.

The firm of Dominica Coconut Products LTD. is a very good example of a local firm that has diversified its product base. This firm is a major exporter of non-traditional products i.e. soaps and toiletries and coconut oil. The name "Coconut Products" is significant, however, if one went into the factory today one would find a variety of products which have no direct connection with coconuts, but use the same services. the same basic equipment e.g. laboratory services.

Increased productivity within the fresh fruit trade is also very important. If real diversification is to take place, then the process should be started within the crop itself. To simply expand the range of crops grown, without any further development, does not fulfill the mandate of diversification. Both primary products and products which have generally reached the mature phase of their life cycles, are usually not great earners of profit. Even the new exotics are no longer attracting the kind premium prices they once did. There has been a rapid movement through the product life cycle with the result that the initial investment in producing and promoting the crop can no longer be recouped. The hard exotics never quite made it to the mainstream market and has been predicted not to do so in the near future.

Further expansion of the agricultural sector is dependent on aggressive marketing organizations, linked to a secure production base ,within an environment conducive to sustainable growth and development. Three vital functions must be present and properly coordinated- namely research, production and marketing at the level of the enterprise. The services such as transportation, finance and communication which are vital to the support of the development of any sector, must be available.

In the international marketplace, consumers have developed very sophisticated tastes and demand products of high quality. At the same time, large multinationals are able to influence these tastes,

through sophisticated promotional campaigns. These multinationals have invested in production and marketing as well as agro-processing and downstream services such as transportation, marketing and research and development. These companies, are about the only ones that can survive the downturn in the market for fresh and processed agricultural products. If small states are to compete successfully, then the entire economy must be market driven with forward and backward linkages in key sectors to allow for sustainable growth and development in the agricultural sector. Agriculture cannot remain viable simply by expanding the range of crops grown. The finance required to drive the economy cannot come from only primary production or limited processing of the primary products. Product differentiation must be extensive. There must be the development of complementary services to support the efforts in the agricultural sector.

Diversification should take place within the crop through agro-processing, at the farm level through increased productivity of crops cultivated, at a company level through the provision of the goods and services and at the national level, by development of all sectors. At the level of the crop, diversification should take place with both forward and backward linkages, with the development of the ancillary services, and with farmers as investors in all the critical elements, ensuring that they can benefit to the maximum. At the level of the enterprises engaged in agro-processing, a similar diversification should take place, with enterprises, always seeking to be responsive to the market place and at the same time not becoming a dinosaur. At the level of the economy, it is not prudent to rely on one sector, even if that sector is diversified. For that main sector itself, to survive, it needs to exist in a vibrant healthy economy. One where services and goods are produced as competitively as possible, are interdependent and give critical support to each other.

TABLE I

SUBDIVISION OF ESTATES

ESTATES	TOTAL AREA (acres)	No. of Lots by Size (acres)						TOTAL LOTS
		0-5	5- 10	10-15	15-20	20-25	25-30	
Soufriere	693.68	87	10	-	-	-	-	97
Geneva	1380.	360	17	-	-	-	-	377
Melville Hall	687.77	67	48	14	15	5	2	151
Castle Bruce	1846	162	71	3	-	-	-	236
Blenheim	696	58	30	-	-	-	-	88
New-foundland	560	6	27	3	-	1	-	36
TOTAL	6000	800	200	-	-	-	-	1000

All areas are in acres
Source:Lands and Surveys Department,Ministry of Agriculture,Dominica.

TABLE II

DOMINICA
GROSS DOMESTIC PRODUCT
at Factor Costs, Constant Prices
(in millions of Eastern Caribbean Dollars)

SECTORS	1980	-	1990	1991	1992	1993P
Agriculture	64.12	-	92.49	92.49	94.65	93.03
Mining and Quarrying	1.48	-	3.08	2.60	2.92	3.04
Manufacturing	13.58	-	26.43	27.49	29.60	30.04
Electricity and Water	5.64	-	11.18	11.92	13.15	13.41
Construction	21.15	-	28.16	28.70	28.50	29.64
Wholesale and Retail	23.93	-	41.07	42.30	43.48	44.66
Hotels and Restaurants	3.07	-	7.63	8.02	8.96	10.09
Transport	18.42	-	36.18	34.94	36.72	37.78
Communications	6.87	-	23.66	28.38	31.61	33.19
Banks and insurance	28.00	-	41.65	48.88	47.81	48.78
Real Estate and Housing	11.28	-	13.51	13.77	13.91	13.95
Government Services	54.51	-	69.01	70.07	70.07	71.47
Other Services	2.85	-	3.90	3.98	4.06	4.14
Less Imputed Service Charge	14.05	-	28.11	36.03	36.40	37.13
Total	240.85	-	369.84	378.31	389.04	396.09
Growth Rate	na	-	6.34	2.29	2.84	1.81

Source: Central Statistical Office, Ministry of Finance, Dominica and OECS Secretariat.

TABLE III

AGRICULTURAL PRODUCTION
(tonnes)

CROP	1984	1987	1990	1991	1992
BANANA	41,177	67,725	66,706	66,679	58,512
OTHERS	53,575	69,131	77,556	69,038	n.a.
TOTAL	94,752	136,856	144,262	135,717	n.a.

Source: Central Statistical Office,Ministry of Finance Dominica.

TABLE IV

EXPORTS
(tonnes)

CROPS	1984	1987	1990	1991	1992
BANANA	32,632	63,682	58,603	56,740	58,024
OTHERS	5,002	5,390	5,723	5,719	7,050
TOTAL	37,634	69,072	64,326	62,459	65,620

Source: Central Statistical Office, Ministry of Finance Dominica.

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[1] Negotiations are currently taking place between the four Windward Islands and Geest Industries PLC. Areas under consideration include: price, transportation and handling of the commodity at the local ports

[2] E.Thor and N. Conklin - "Pesticide Regulation and Inter-American Trade" -1994

AGRICULTURE AND THE ENVIRONMENT

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ABSTRACT

This paper examines the evolution of agriculture and its relationship with the environment, through the various phases of its development. It traces man's food- gathering and food-producing activities through various phases of cultural advancement, up to the present time, identifying their impacts on the environment. In each phase of advancement the paper examines the influence of population growth, and science and technology on the evolution of agricultural practice. With the aid of science agriculture has become quite efficient, but still is not without some negative repercussions to the environment (Carson, 1962). For the future, agriculture has to become even more efficient, given projected increases in population.

This expository paper notes, though, that growth in agriculture cannot be expected to increase without limits, in view of environmental constraints. Growth therefore has to mean more than just a quantitative increase. The challenge then, is to fashion a meaning of growth consistent with the limits of the natural system and, for food production systems to meet the needs of burgeoning populations in a manner which will not excessively degrade the ecology which supports them. To meet this challenge, the paper identifies changes we need to make: in the way we apply science to solve problems in agriculture, in our approach to policy formulation and, in the way we organize institutional response to meet future challenges.

INTRODUCTION

Social scientists have long been intrigued by man's engagement with nature. Indeed, continuing research has shown that modern man is as much driven now by his need to triumph over the elements as was his historic counterpart centuries ago. Today, even while man waits at the equinox of a new millennium, his struggle for survival is still dependent on that aged relationship between himself and nature.

This paper discusses how man's agricultural practices throughout history have caused or precipitated certain negative environmental changes. Further, this paper suggests that these negative results of man's use of nature may be short-circuited and minimized through a process of cultural adaptation.

Through such a process, the careful and beneficial use of science and technology may be encouraged toward extracting the resources our natural systems provide, without harming the systems themselves.

The environment is a matrix of ecosystems supporting life. Each ecosystem is a self-regulating, self-sustaining community of plants and animals locked into relationships with each other and the surrounding elements. This set of interconnected and interacting units of living and non-living things produce the goods and services on which man depends.

From the earliest of times man depended on the environment for food and shelter. This relationship between man and nature evolved through a number of distinct stages. Each stage of the relationships had a feature which distinguished its impact on the environment.

Miller (1975) identifies five phases of cultural evolution and their repercussions on the environment. The five stages are:

- early hunter-gatherer;

- advanced hunter-gatherer;
- shepherd and farmer;
- industrial man;
- earthmanship man.

Conceptually, his impact on the environment at each stage may be summarized as follows:

Early hunter-gatherers and advanced hunter-gatherers are viewed as man in nature. Their relationship with nature was non-manipulative, any negative impact on the environment was relatively benign and the rate of recovery of the environment was quite swift.

Shepherd, farmer, and industrial man are viewed as man versus nature. Rudimentary attempts at manipulation by people in these groups can impact on nature quite severely. The damage can persist over a long period of time and the rate of recovery is often slow.

Man is said to be in a state of earthmanship when he is living within the limits of natural systems. Earthmanship allows man to develop an awareness of the limitations he has in respect to controlling nature. Earthmanship allows man to cooperate intelligently with nature. In this phase, Darwin's proposition - "survival of the fittest" - takes on added meaning. In this advanced relationship with nature man interprets Darwin's maxim to mean the "survival of those species most capable of adapting to variations in nature." In its original context, "survival of the fittest" meant survival of the strongest.

The relationships between man and nature described above can be looked at in terms of a gradient - from passive dependency, through aggressive manipulation, to intelligent cooperation. Man in nature, as early hunter-gatherer, took from nature whatever was available in the ecosystem in which he existed at the time. In this relationship with nature, man reaped from the bountiful harvest of nature. He did not produce any of the food he consumed: His role was one of passive dependency. Notably, most of mankind who have inhabited the earth have been hunter-gatherers; only a very small number have lived by agriculture (Lee and DeVore, 1968).

Miller (1975) observes that for most of man's sojourn on earth he was a hunter gatherer. Because of recent cultural shifts, today, less than one percent of mankind is involved in hunting and gathering food. In this phase of the cultural evolution man was entirely dependent on nature. He survived by learning to live within the limits prescribed by nature. During this phase the supply of food determined the size of the population, any increase in population size beyond the tolerance limits is swiftly adjusted by nature. In this situation man learned to respond to nature rather than attempt to control it. Any impacts from this human manipulation were therefore quite mild and within the capacity of nature to remedy.

As advanced hunter-gatherer, man developed more sophisticated tools. He learned to use fire, and through language he was able to pass on his experience to his offspring. Man learned to use fire to clear land and hunt large numbers of animals. Through specialization, he was able to increase his food supply significantly. All this led to him exerting much more pressure on the environment. Martin and Wright (1967) believed that the extinction of some of the larger game animals during the ice age could be attributed to the actions of advanced hunter-gatherers. Man, the advanced hunter-gatherer, altered the vegetative cover of the land by his use of fire.

His experience with the use of fire probably taught him that the vegetative cover that sprang up after burning land provided rather palatable grazing for the animals he hunted. Saurer (1952) and Stewart (1956) believed that repeated burning created the world's savannahs and grasslands. Man had begun to alter the environment in perceptible ways but because of his small numbers, the impact of his actions remained insignificant. Even at this stage man did not develop the capacity to manipulate the environment; he was not a food producer.

As man evolved from advanced hunter-gatherer to shepherd and farmer, his negative impact on the environment peaked. This period of cultural evolution began about ten thousand to twelve thousand years ago (Miller, 1975). The significant development during this period is that man became a food producer by domesticating plants and animals. That is, he was engaged in the

deliberate cultivation of selected plants and the rearing of selected animals. In this phase, man became innovative in his use of existing tools. He became adept at using fire to clear land, using the digging stick as a hoe. Clearing by fire converted forests to savannahs and grasslands. Man used his domesticated animals to graze these grasslands. Grazing, in its turn, resulted in erosion. This pattern of overgrazing was repeated again and again and resulted in the destruction of vast areas of the Mediterranean and Middle East.

It was during this phase of animal rearing and grazing that horticulture (hoe-culture) developed. Man started growing some of his favorite plants as food by digging a hole with his digging stick, and inserting roots and tubers into the ground.

Other innovations during this period included slash and burn horticulture. The ash produced from the burnt vegetation enriched the soil, but the fertility was temporary as torrential rains would leach the soil and wash away the nutrients during rainy seasons. The cycle of burning and leaching would eventually render the cleared plot infertile. To produce food to support the population a new plot of land must be cleared; the cycle is therefore repeated. This method of production persists up to today in many developing countries and is one of the chief means by which the environment is degraded. In many countries there is significant loss of forest cover from slash and burn agriculture. This land degradation has devastating effects on the environment. In Jamaica, for example, it is estimated that loss of natural forest cover is occurring at a rate of five percent per year.

Soon after learning vegeculture, that is the growing of tubers and other plant parts (National Research Council, 1982), man began to plant seed crops, such as barley and wheat. It is believed that cultivation of seed crops began in the Middle East in the area of Mesopotamia (Miller, 1975). Most of the crops like wheat, barley, corn, peas, lentils and potatoes that we cultivate today were being cultivated by man in his role of shepherd and farmer three thousand years ago.

True agriculture began when man invented the plough. Initially, power was supplied by draught animals and then by the tractor. It is here that man became an advanced food producer. With his growing knowledge of food production, he was able to provide a constant supply of food. More importantly, he was able to provide a surplus on a regular basis. This surplus production had three effects:

1. The population increased dramatically;

2. Man cleared vast areas of land and started to grow single crops over large acreage. This marked the advent of monoculture which is characteris of modern agriculture

3. The pattern of dwelling in villages, towns and eventually cities which we refer to as urbanization, became a characteristic of agricultural society. Another distinctive feature was the advent of specialties other than farming. The surplus of food enabled the movement of people out of food production into other areas of endeavor. Urbanization and specialization, ushered in what is now referred to as modern civilization. Man's impact on the environment became severe.

As more and more land was taken up for growing food and rearing animals, deforestation and its resulting erosion caused the silting up of rivers and irrigation canals. This caused a lowering of the water table and the loss of agricultural productivity. It is reported that deforestation accounted for the silting up of the Tigris and Euphrates rivers and the elaborate Babylonian irrigation canals. Saggs (1962) attributes the downfall of the Babylonian empire to the canals' damage and the concomitant losses in agricultural production. Other degrading effects caused by the rising popularity of agriculture include desertification and the extinction of plant and animal species due to the destruction of habitats.

Irrigation without proper drainage and over-pumping led to the build up of salts in topsoil. The build-up later caused a lowering of productivity levels. As the population grew, the clearing of

more forests to free up land for food production became necessary. The land clearing resulted in erosion, as well as the pollution of streams, rivers and lakes. Clearing these forests also increased the insect and pest population.

The advent of agriculture marked a radical shift in man's relationship with nature. He began to manipulate the environment to satisfy his needs. This is in contrast to man as hunter-gatherer who chose to live in harmony with the environment. Through progressive cultural adaptations man became increasingly adept at manipulating the environment. He learned to use tools for hunting and gathering food, learned to live in a hostile environment by developing means of efficient social organization and cooperation, and he used language to convey the knowledge he was acquiring from his experiences (Miller 1975). As the cultural evolution progressed, man became even more adept at manipulating the environment as he learned to apply scientific principles to his food producing activities. From studying this phenomenon of cultural evolution, one can say that modern agriculture is the product of progressive cultural adaptation, with particular strong influence from science and technology.

The development of modern agriculture can be traced through three phases:

1. The Industrial Mechanical Phase:
   Here the application of mechanical power enabled man to transform large acres of forest and grass land into cultivated land. This led to massive conversion of forests and natural grasslands into monocultured fields of crops which in turn resin habitat loss, soil erosion and the emergence of insect and plant disease as important threats to crop culture.

2. Chemical Industrial Phase:
   Here, man through the application of science developed fertilizers, weedicides, insecti cides and growth regulating substances was able to produce more per unit of input. The insecticides and weedicides were required to protect the expansive fields of monocultured crops from fierce competition from insects and weeds. When there is innovation in the application of fertilizer, insecticide, weedicides, plant breeding and irrigation technologies--which result in increased production over large areas--it is referred to as "green revolution" (Miller, 1975). There have been four major green revolutions:

i. During AD 1500 to AD 1800 when the major crops - wheat, rice, maize and potato - were spread throughout the world.
ii. 1850 to 1950 - the period saw intensive application of scientific principles to crop and animal production. This occurred in North America and Europe.
iii. Post World War II innovations in plant and animal breeding which produced varieties which were more resistant to disease and insects.
iv. This particular episode of the green revolution, which occurred in developing countries in recent times, was widely heralded. Really, it only entailed the adoption of the scientific principles of the second and third green revolutions by developing coun tries. The main effect was to introduce high yielding varieties of rice, maize and wheat into developing countries. In this phase of agricultural evolution, man's manipulation of the environment rose to new levels. Even though agricultural production was significantly increased and Malthusian's starvation long predicted was averted, there were serious environmental impacts.

The seminal work of Carson, (1962) awakened us to the dangers of man's excessive manipulation of the environment through the application of science to agricultural production. There are many arguments that the gains made were probably neutralized by the adverse impacts produced by the use of the technologies developed in this era. Some of the significant impacts include the magnifi-

cation of insecticides in the food chain, and alteration of the structure of ecosystems as a result of insecticide use, which killed targeted insect pests as well as others of the non-target insect population. Another important impact was the pollution of rivers and lakes and underground water systems from leached insecticides and fertilizers. This situation posed a serious health threat as food was often contaminated by chemical residues. Another impact was the loss of bio-diversity which was the basis for improvement in animal and crop production through breeding, and the threat of monoculture to genetic diversity among cultivated plants.

3. Biotechnology Information Phase:
   In this phase the innovative application of genetic engineering and computer technology promises to revolutionize agricultural production. There are risks associated with the application of biotechnologies to agriculture. Their impact seems to be uncertain at this time.

Some writers though have been pointing out the positive effects of genetic engineering (Wagner 1986, Peterson and Swinton, 1992). It is felt that new plant and animal varieties will cut production cost, cut processing cost while adding desirable marketing qualities. A reduction in production costs will lead to the conservation of resources. Additionally, insect and disease-resistant plants may lead to less use of pesticides, thus reducing the environmental threat from these chemicals. It is also envisioned that new varieties will be more efficient in their use of fertilizers: another positive for the environment since using less fertilizer will reduce the threat of contamination to steams, lakes and underground water systems. On the other hand, the information age ushered in by advances in computer technology will promote ecosystem based farm management. Computer models will facilitate agro-ecosystem analysis and forecasting of changes within and among ecosystems. The obvious challenge in the application of genetic engineering technologies is to protect the environment from the ill effects of engineered genotypes. It is hard to imagine having technological advancement without risk, so the key to successful use of these technologies (with the minimum danger to the environment) is being able to assess the nature and degree of risk associated with them. In fact, systems to reduce and manage risk must be developed. The application of computer technologies should provide avenues to accomplish reasonable risk analysis and management.

It is clear that the evolution of agriculture or man's food gathering activity and food producing activity from the early phase of hunter gatherer up to modern agriculture has traced a path of increasing intervention by man with concomitant increase in the severity of negative impacts.

In spite of these negative impacts, man was able to increase agricultural productivity dramatically, thus making food available to an increasing number of people. In other words, food production has managed to keep apace with population increase. There are predictions for further population growth, especially in developing countries. Mann (1994) reports that the world's population is likely to increase between 10 and 12 billion by the year 2100. To meet the food needs of this projected increase in population, there has to be further increase in agricultural productivity globally.

Can improvements in agricultural productivity without negative environmental impacts be expected? Many believe the answer to this question is "No." Mann (1992) refers to an analysis by Ehrlich which points out that mankind has already used or destroyed fifty percent of the potential output from terrestrial photosynthesis and if the world's population doubles, this would put mankind in severe competition with insects over the last scraps of grass. But, there are others who think that technological improvements will lead to even more advancements that will ultimately meet the future needs of a growing population.

In support of the latter view, it is noted, however, that not only did farmers keep pace with food production, but per capita food production on a global scale rose more than ten percent over the period 1968 to 1990 and the number of chronically malnourished people fell by more than 16 percent (Mann, 1994). Still, there is need to assess the environmental impact of this growth in food production.

Thermodynamically, growth without limit is not possible (National Research Council, 1992; Miller, 1975; and National Round Table on the Environment and Economy, 1992). The ecosystems of the earth produce a finite amount of goods and services, that is these systems are in a steady state of equilibrium. This fact limits the quantity of goods and services which man can extract through manipulation of these natural systems.

Furthermore, the second law of thermodynamics tells us that as man attempts to create greater order by applying advanced technologies to increase agricultural production one result will be a net increase in disorder of the system and its environment taken as a whole. For example, breeding more productive plants and animals will require greater protection from disease and insects, as well as the more intensive use of insecticides and fertilizers which increases the potential for pollution: the entire process resulting in net disorder.

The first law of thermodynamics states that energy can neither be created nor destroyed. This implies that within the ecosphere there is a fixed amount of energy available to drive natural or manmade systems. It is clear then that these two laws taken together put a cap on the productivity of natural systems.

Development then, as used in the phrase "sustainable development," cannot mean unlimited quantitative increase in food production. In other words, development in this context cannot be synonymous with growth because nothing in nature grows limitlessly. Sustainable agricultural development means improving the capacity of mankind to convert a constant supply of resources to the increased satisfaction of human needs. Development as a concept, therefore, should be expanded to include differentiation, qualitative improvements and synergistic effects.

The challenge then for agriculture is to identify opportunities where the principles of an amplified concept of development can be applied to provide adequate food at reasonable cost for the world's population without irreversibly degrading the natural systems on which it depends. No single strategy will enable mankind to meet this challenge. Technology by itself (as some believe) will not resolve the problem, neither will population control.

A more robust perspective of development must be applied across the board, and to a large number of strategies which include scientific and technological approaches, population control, institutional innovation, and cultural adaptation.

The problem of agricultural development in the context of finite resources is concerned with the reconciliation of primary issues:

(1) limits imposed by the natural system and/or the ecological ceiling, above which the ecosphere cannot support life, and

(2) the efforts of humans to satisfy their need for food and fibre from the resources and services provided by the system.

The first is quite rigid. We are unable to amend the laws of thermodynamics which prescribe the outer limits of its boundary. The ceiling imposed by the natural system is not subjected to alterations through manipulation by mankind. However, the second factor is quite malleable and is subjected to manipulation. Really, the best hope of achieving sustainable agricultural growth is to make a concerted effort to change the way in which man relates to the environment. It could be said that we need to undergo a cultural revolution.

Culture, here, refers to an accepted set of beliefs, values and particular ways of doing things which have evolved over several years and have proved to be useful in promoting the success of human endeavours. Such a revolution would entail adopting innovative approaches to creating and operating the institutions through which we respond to and interact with the environment. The fairly stable and integrated set of roles and streams of processes (institutions) which we employ to produce the wide variety of goods and services should be designed as flat, fluid and flexible, but, allowing the performance of job tasks. There should be adequate process capacity to handle large

volumes of information, resolve conflict, conserve human resource, encourage enquiry and independent thought. The institutions through which we will act to respond to environmental imperatives should emphasize the importance of structure in determining the character of the institutional processes and behavior.

The second aspect of the cultural revolution should address changes in the way we apply the scientific method to solve problems in agriculture. Because of the large volume of information that science ordinarily deals with, knowledge is compartmentalized into disciplines.

Each discipline, develops its own traditional ground rules and approaches to problem-solving; thus producing a fragmented approach to the process of finding solutions. But problem-solving would likely be more effectively achieved if there was a way to integrate the disciplines with certain pervasive problems. Even within disciplines, there isn't a coherent approach to selecting the types of problems to be solved. This tradition of categorization and fragmentation deprives science of the benefits of synergy.

The artificial system set up to categorize knowledge may have influenced the actual application of the scientific method whereby a problem is reduced to its simplest form in search of a solution. After formulation of the solution, the complexity of the phenomenon is usually not reconstructed in order to restore linkages, this usually results in loss of fidelity and failure to identify significant interactions. If, in the application of science it was possible to apply problem solving techniques without over-simplifying the phenomenon under study, we might be able to formulate solutions which would have taken into account the external linkages originally characteristic of a complex phenomenon.

Ecosystems - with their interconnections and interactions - are truly complex phenomena. If these interactions and interconnections are broken to simplify the system (to make it amenable to analysis), then the system loses its fidelity, so what is studied or analyzed is not really the system. The situation is made even more unrealistic since no attempt is made to re-establish connections after a solution is proposed. So, knowledge gained is usually inadequate and not sufficiently general to hold over varied conditions and settings.

For agriculture to develop sustainably, a scientific method will have to be defined to take into account the complex nature of ecosystems and make adjustments to study them with their interconnections in place as much as is possible. This will require a re-orientation of our thinking. That is, we have to become system thinkers, applying what Peter Senge calls "the fifth discipline." (Senge, 1994).

This paper suggests that cultural adaptation, as here described, is a faster way to adapt. It is much quicker than the biological way of the double helix of genetic material. Palmer (Dialogue No. 4, 34, 1992) suggests that cultural adaptation is much quicker than genetic adaptation.

The challenge that man has today is to satisfy human needs from the resources that natural systems provide, and still put these life-supporting systems at minimum risk. Given this challenge, development in agriculture must look to exciting and innovative ways of using the instruments of our culture--namely science, technology, methods of cooperating and organizing--to communicate with nature.

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AN EVALUATION OF THE REGIONAL EFFECTS OF NEW CITRUS DEVELOPMENT ON THE ECOLOGICAL INTEGRITY OF WILDLIFE RESOURCES IN SOUTHWEST FLORIDA

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ABSTRACT

State of the art methods in landscape ecology, impact assessment and environmental planning were applied to evaluate the regional effects of citrus development on the ecological integrity of southwest Florida. The 600,000 ha study area borders the environmentally sensitive Everglades and Big Cypress areas and is prime habitat for the endangered Florida panther. Citrus development alters existing landscape conditions, and there is concern that the scale of the proposed citrus development could effect regional ecological resources. Evaluation of the effects of citrus development focused on listed species, vulnerable habitats and regional biological diversity. The foundation for the conservation of regional ecological integrity will be a mosaic of different intensity land uses.

INTRODUCTION

This study is an evaluation of the short and long-term effects of new citrus development in southwest Florida. Since the introduction of citrus to the St. Augustine region of north Florida in the 16th century the citrus industry has been moving south. Following a series of devastating freezes in the early 1980s there began a major shift in the geographic distribution of citrus within Florida. Growers, seeking to reduce the risk of freeze damage, are relocating to the Gulf Coast region of the state. Since 1980, citrus acreage in the region has doubled to the current 60,000 ha. This trend is expected to continue through the next decade with a projection of 80,000 ha in production by the year 2000 (Land, 1988). The on-tree value of this production, given current citrus prices, is estimated to be 380 million dollars annually (Behr, 1989). Therefore, this industry is a major contributor to the economic well-being of southwest Florida.

However, there is concern that the scale of these developments will significantly affect the ecological integrity of the region, which borders the environmentally sensitive Everglades National Park and the Big Cypress National Preserve (Figure 1). Much of the current and proposed citrus development is occurring in an area occupied by a diverse native flora and fauna including 31 species listed by state and federal agencies as endangered, threatened or a species of special concern, such as the Florida panther. Consequently, there is concern about what the effects of citrus developments will be on the habitat of native species.

PROJECT AREAS

There are five major aspects addressed in this report. 1) Historic and current land cover and land use of the study area including maps of *c.* 1900, 1973 and 1989 land cover, boundaries and status of permitted citrus and public land boundaries. 2) The importance of different habitats for

vertebrates within the study area based on the literature and field sampling including wildlife use of citrus groves and prairie/flatwoods ponds. 3) A citrus feasibility evaluation in which each section within the study area is given a ranking (high, moderate or low) of its feasibility of conversion to citrus based on soil characteristics and landownership. 4) An evaluation of the potential effects of continued citrus development on wildlife and habitats using species models and alternative development scenarios based on the citrus feasibility section. 5) Recommendations for mechanisms for integrating wildlife and habitat protection with citrus development.

Figure 2 represents the scientific approach applied during this study to integrate the conservation of ecological integrity with agricultural development.

RESULTS AND DISCUSSION

Land use and vegetation cover maps from *c.*1900 and 1973 show that historically the area was a mixture of wetlands (61% of the area) and uplands (39%) dominated by pine flatwoods (29% of the uplands) (Figure 3). By 1973, 36% of the total study area had been changed from natural to agriculture and 3% from natural to urban/industrial uses. The conversion of natural areas to improved pasture accounted for the majority of the land use change (130,294 ha, 2.4% of mapped area). Citrus made up 14,130 ha, 2.7% of the study area and 7.2% of agricultural use. These changes affected 37% of the wetlands and 43% of the uplands. Currently, the largest cover types in the Immokalee Rise area are modified land covers. Citrus and vegetable crops, and pasture/range each account for approximately 23% or 143,000 ha of the total area. Citrus makes up 10% of the total land use and 44% of agricultural lands. Forested areas are about evenly divided between pine and cypress; 72,000+ ha or 11% each of the total study area. Marsh classes make up another 10% (65,000 ha) of the total. Marsh classes are of interest because in addition to the larger sloughs, there are numerous discontigous wetland depression scattered within the pine flatland/rangeland ecosystem. These small depressions taken together, have considerable impact on the landscape. Freshwater marshes and pine forests are the areas of greatest loss since 1900 with 51% and 88% (respectively) of the 1900 area converted to other uses.

Eight percent of the study area (49,770 ha) is in public or private ownership intended for natural resource conservation and is therefore protected from development. Three percent (18,873 ha) is in public ownership with goals other than conservation (State Indian Lands). An additional eight percent (52,205 ha) has been proposed for protection by state and federal agencies. About 10% of the existing and proposed protected areas is marsh and 10% is pineland. Although similar to the current proportion of these cover types in the region the proportion of marsh and pineland cover in protected areas is less than the historical values and is unevenly distributed in the region (concentrated in the southern portion).

Three hundred eighty vertebrate taxa were identified as occurring in the region. Three hundred sixty-two are native species; 18 are non-native. Of the cover types examined, forested uplands had the most number of native species (182) using it for any activity followed by range (178), wax myrtle and willow (172), freshwater marsh (172), cypress forest (172) and pine flatwoods (169). Pine flatwoods had the most number of species (54) using it as critical habitat followed by freshwater marsh (42), hardwood swamp (31), and lakes and ponds (23). Based on a composite ranking of species use and abundance freshwater marsh, forested uplands, pine flatwoods, and range are the most valuable habitats for wildlife in southwest Florida. These are also the cover types that are most vulnerable to citrus development.

Fourteen sites were used for determination of species use of citrus groves and prairie/flatwoods ponds. Two hundred seventy-five species were observed through out the study area. Citrus groves (all cover types) have a relatively high species richness (203 species); however, the majority of species (159) were observed in agricultural reservoirs. One hundred six species were observed in grove beds of all ages; however, grove beds varied in their suitability as wildlife habitat. Sixty eight species were observed in young grove beds, 93 in intermediate-age grove beds and 68 in

mature grove beds. Factors in addition to age that may have affected the species richness of these grove beds include: size (groves ranged in size from 8 - 2,400 ha), interspersion of other critical habitats, sampling effort (the young grove was sampled continually), proximity to large natural areas (sample sites ranged from 4 - 12 km from Corkscrew Swamp or Okalacoochee Slough), visibility of wildlife in groves of different ages or effects of workers on wildlife (especially snakes). Groves less than 500 ha had fewer species than larger groves. The absence of data from groves between 1,000 to 2,000 ha limits our ability to describe species area relationships for citrus groves. Development of citrus groves does not create biological deserts. In fact citrus groves had a relatively high species richness (over 50% of the native species known to occur in the region were observed in citrus groves). However most of these species (159 out of 203) were observed in agricultural reservoirs, which in most locations are natural wetlands that have been incorporated into on-site wet detention areas. Grove beds had fewer species (103 over all ages) than reservoirs and varied in their suitability as wildlife habitat (Figure 4). The pattern observed here of intermediate aged systems having the highest species richness is not unusual (Connell 1978, Maehr 1984).

Five prairie/flatwoods ponds (temporary ponds) were sampled for wildlife use. One hundred thirty eight species of wildlife (more than one-half the species observed in this study) and 96 species of plants were observed. Ponds varied in size, shape and species composition. Fifty percent of the plant species and 31% of the animal species were found at only one pond; conversely only 3% of the plant species and 17% of the animal species were observed at all ponds. Wildlife use of temporary ponds in southwest Florida exemplifies the importance of linkages between upland and wetland cover types in providing wildlife habitat.

The citrus feasibility portion of this study was conducted to predict the extent and pattern of future development. The two major aspects of the study area that were deemed most important in determining possible expansion of citrus development were a) the likelihood of the landowner to develop land for citrus, and b) the ability of the soil to support a viable citrus grove.

For the soil feasibility ratings, 39% of the sections were rated as most feasible, 40% of the sections as intermediate feasibility, and 21% of the sections as least feasible. Most existing southwest Florida citrus groves have been planted on category 1 and 2 soils, thus these two categories may be considered together as feasible citrus sites. The majority of the sections surveyed contain soils that could support viable citrus groves, provided that proper drainage systems are in place. Most of the sections with soil ratings of 1 or 2 are located towards the north part of the study area, in Hendry and Glades counties.

Three different development scenarios were run to determine their impact on available habitat and on selected species. Under the first development scenario (Dev. 1) all land that has a final feasibility ranking of 1 is converted to citrus. In development scenario 2 (Dev. 2) land ranked 1 or 2 is developed as citrus and in scenario 3 (Dev. 3) land ranked 1 or 2 is developed as citrus and truck crops are added in areas classified as 3.

Most of the land to be converted to citrus is currently range or pasture. Uplands followed by wetlands are the cover types next most vulnerable to citrus development. Most of the current habitat is lost between development scenarios 1 and 2. In addition to loss of habitat another consequence of citrus development will be fragmentation of the remaining habitat patches. It is important to emphasize that these effects on existing habitat conditions (amount and contiguity) are predicted to occur in the absence of any environmental planning and regulation and overestimate the losses of wetlands that will actually occur.

Thirty-five evaluation species were selected to forecast the effects of citrus conversion on wildlife. Evaluation species were selected on the basis of being important ecologically, and/or economically, and representing important habitats or habitat relationships. To focus on particularly important ecological relationships sandhill crane, panther and wading birds were chosen for species modeling.

The status and habitat relationships of the 35 evaluation species (or groups of species) and the probability of species persistence in groves, with and without new design recommendations was based on field observations and expert opinion. With no further design changes, nine of the evaluation species are likely to persist in groves and an additional eight may persist. By making changes in grove and reservoir design 13 of the key species will be likely to persist in a citrus grove and 15 might be able to. The species not likely to persist within a citrus grove are those with very large home ranges (panthers) and/or those that require large intact old growth forested areas (hairy woodpeckers). The single most important feature for grove design is to encourage the incorporation of uplands into the grove landscape whenever possible. Permanent water holes should be created where appropriate to further enhance habitat diversity in agricultural reservoirs.

RECOMMENDATIONS

To be successful, an ecological conservation plan has to be implemented in an arena influenced by economic, legal, social and political factors. Efforts to conserve the ecological integrity of southwest Florida can ill afford the adversarial relationships that too often characterize participants in environmental planning. Mechanisms must be found to compensate (or provide incentives for) landowners asked to forgo intensive development of their land. Only in this manner is it possible to avoid the issue of the taking of property rights, and to change a normally win-lose situation into a win-win one.

1. Forested upland habitats, especially pine flatwoods, must be protected to conserve the ecological integrity of southwest Florida. Protecting uplands not only protects species but also is essential to maintain significant wetland wildlife functions.

2. The foundation for the conservation of fish and wildlife resources with continued citrus development will be a regional landscape that is a mosaic of different intensity land uses.

3. Whenever possible the issue of the taking of property rights should be avoided by providing compensation or incentives to landowners asked to forgo more intensive development of their property.

4. Develop a comprehensive plan for the conservation of ecological resources, with regional policies and measurable goals for the conservation of ecological resources.

5. A system for evaluating the ecological functions of an area should be developed and applied to provide more detailed inventories of predevelopment ecological conditions and to provide a more complete evaluation of the "success" of mitigation.

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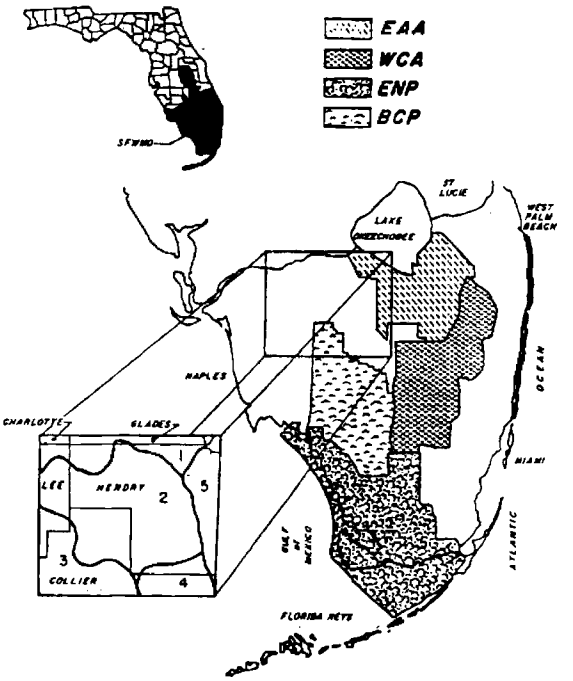

Figure 1: Relationship of study area to neighboring ecological and agricultural areas (EAA-Everglades Agricultural Area, WCA - Water Conservation Areas, ENP - Everglades National Park, BCP - Big Cypress National Preserve) and physiographic regions (1 - Caloosahatchee Valley, 2 - Immokalee Rise, 3 - Southwestern Slope, 4 - Big Cypress Spur, 5 - Everglades, SFWMD - South Florida Water Management District).

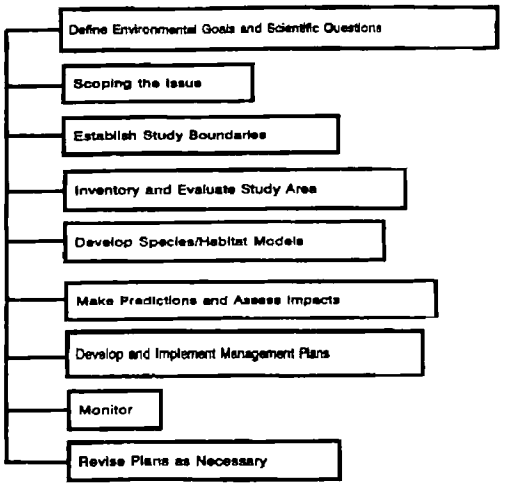

Figure 2: Scientific framework for integrating conservation of ecological integrity with agricultural development

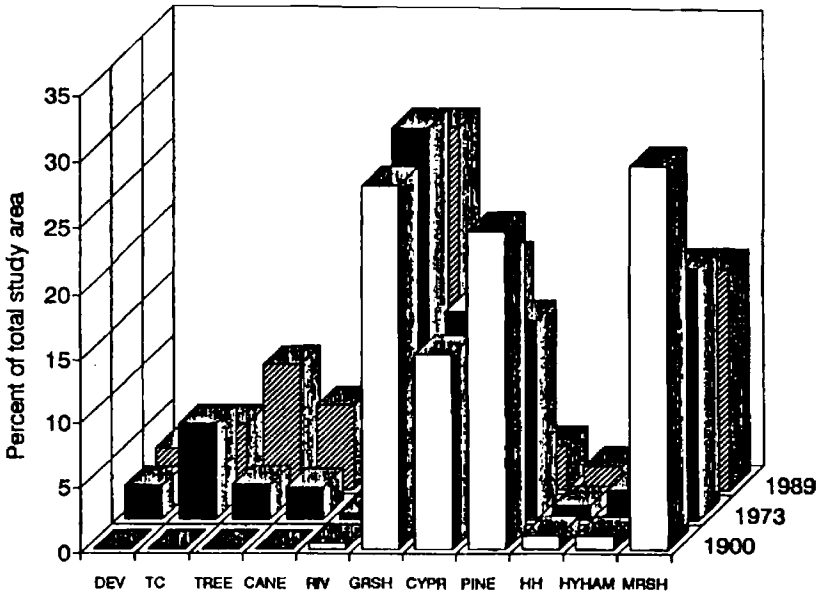

Figure 3: Percent change in selected cover types from 1900 to 1989. DEV - developed areas, TC = truck crop, TREE - tree crop, CANE = sugar cane, RIV - laucustrine and riverine systems, GRSH = grassy shrub, CYPR = cypress, PINE = pineland systems, HH = hardwood hammock, HYHAM = hydric hammock, MRSH = freshwater march systems.

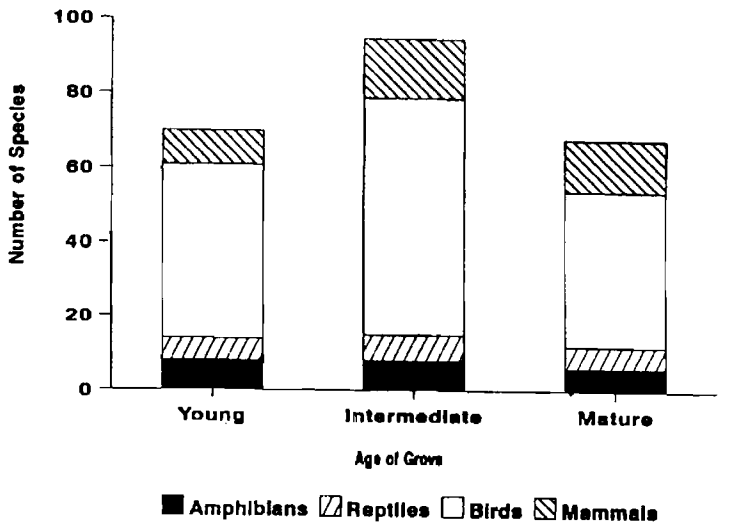

Figure 4: Number of vertebrates observed in different age groves from June 1990 through June 1991.

THE POTENTIAL OF USING CONSTRUCTED WETLANDS TO TREAT ANIMAL WASTE IN THE VIRGIN ISLANDS

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ABSTRACT

The increase of intensive livestock farming in the Virgin Islands, most recently with the addition of a 400 animal unit dairy on St, Croix, can lead to a subsequent decrease in coastal and ground water quality due to pollution from animal wastes. Confining livestock to smaller areas to improve production efficiency also concentrates animal wastes. Runoff of these wastes to nearby guts or leaching into groundwater aquifers can contaminate waters with bacteria, nutrients, BOD and TSS (total suspended solids). Removal of riparian vegetation (vegetation native to guts and natural drainages) to increase available acreage, vegetation depletion by livestock grazing and loafting activities, and direct access of livestock to streamside areas has eliminated the buffer strips that formerly protected from direct pollution. Affordable, effective wastewater used for human consumption. Constructed wetlands are being used increasingly to treat both municipal and agricultural wastewater in the United States with great degrees of success. This innovative wastewater treatment practice has potential for use in the Virgin Islands to inexpensively and effective remove pollutants from wastewater and protect the quality of our waters.

INTRODUCTION

THE ADVERSE EFFECTS OF ANIMAL WASTE

Runoff containing animal wastes can pollute surface and ground water, contaminating local drinking water supplies and coastal waters. Animal wastes include manure, washdown water, cleaners and disinfectants, feed, and product waste (spilt milk, broken eggs, etc.). One cow can produce as much waste as 11 people; pigs produce 6-8 pounds of manure per 100 pounds weight per day; one chicken house can produce 10 tons of waste per day (U.S. EPA, 1993).

Animal wastes contribute oxygen-demanding substances, nutrients, organic materials, suspended solids and pathogens to receiving waters. The decomposition of organic materials can deplete dissolved oxygen supplies in water resulting in anoxic conditions. Methane, amines, and sulfide are produced in anoxic waters, causing the water to have an unpleasant odor, taste, and appearance. This renders coastal waters unsuitable for fishing, swimming and other recreational uses (U.S. EPA, 1993).

Suspended solids and nutrients in animal wastes deposited into waterbodies can accelerate eutrophication by encouraging excessive algal growth. Excessive algae and sediments smother coral reefs and seagrass beds, decrease light penetration for aquatic plant growth, and smother bottom-dwelling organisms. This increased turbidity can also interfere with fish feeding and spawning habits.

Animal diseases can be spread and/or transmitted to humans through contact with animal feces. Runoff from pastures, feed lots and other animal facilities can contain extremely high concentrations of bacteria and other pathogens. These high concentrations can lead to beach

closures, contaminated shellfish, and contaminated drinking water.

Livestock wastewater has a number of different sources -- feedlots, milking parlors, loafing areas, housing facilities, manure storage and application areas, and pasture runoff. This waste is a major management problem for farmers due to a number of factors: high waste strength and volume, high construction and operation costs for treatment, lack of adequate land disposal areas, time consuming and labor-intensive operations, and lack of technical information and financial assistance.

ANIMAL WASTE IN THE VIRGIN ISLANDS

There are currently 6 dairy, 100 livestock, and 3 poultry farms in the Virgin Islands (USVI Bureau of Economic Research, 1990). In 1987, these facilities produced a wide variety and number of animals:

Type of Animal	Number
Horses	324
Sheep	3134
Goats	3315
Hogs	2536
Cattle:	
Cows	2499
Heifers	1130
Bulls	488
Chickens	5326
Turkeys and Other	727

Given the environmental conditions of the Virgin Islands -- steep slopes, high intensity rainfall events, close proximity of any given area to coastal waters, shallow depth to fractured bedrock, clayey soils, and unconfined aquifers -- animal wastes can rapidly and easily enter both surface and ground waters where they can contaminate drinking water supplies and coastal waters. Few farms have sufficient waste storage and treatment facilities and many allow animals to stand or wallow in guts and ponds, directly polluting surface waters.

There are presently no large confined feedlots (greater than 150 head) in the Virgin Islands. However, there are approximately sixteen small feedlots (for hogs and dairy as well as poultry facilities) on St. Croix and St. Thomas. Waste treatment systems that are typically used at these facilities consist of lagoons that only provide partial treatment, removing settleable solids and some BOD5, with effluent from the lagoons then discharged into guts.

Currently, a large dairy has completed construction on St. Croix. It will start operations with a 200-head fully confined animal facility utilizing a solids separator to process all washwater and product waste. Effluent will then flow into an aerobic lagoon for treatment to remove further suspended solids (TSS) and BOD5, with resulting effluent to be used for improved pasture irrigation.

Due to the scarcity of water in the Virgin Islands, as evidenced by our current drought, many agencies and individuals have been looking into similar types of systems to reclaim wastewater (both agricultural and municipal) for irrigation purposes. One system with great potential for application in the Virgin Islands is a constructed wetland system (or artificial wetland).

ALTERNATIVE WASTE TREATMENT METHODS -- CONSTRUCTED WETLANDS

A constructed wetland is an aquatic ecosystem with rooted emergent hydrophytes that is designed, constructed and managed to treat agricultural or municipal wastewater. These systems build on the physical, chemical, and biological processes inherent in wetlands in order to treat

wastewater naturally instead of using complicated and expensive mechanical systems. The interaction of plants, microscopic organisms, aerobic and anaerobic substrates, and a meandering water column can remove nutrients, organic compounds, pathogens, and metallic ions and increase oxygen and pH levels in a variety of wastewaters (TVA, 1992). The most frequently recommended type of system is a surface flow constructed wetland in which wastewater flows across plant beds within a basin or cell that also has a free-water surface.

Constructed wetlands are easy to design, build, maintain, and operate as compared to mechanical systems. They are an affordable, effective, and environmentally pleasing method of protecting water quality. In a typical constructed wetlands treatment system, depending on pre-treatment and target discharge levels, construction costs range from 10% to 50% less costly as compared to conventional treatment systems, and operation and maintenance costs are 5% to 10% of conventional treatment costs (TVA, 1992).

In an ideal system, wastewater is distributed evenly across the surface of the constructed wetland, which generally consists of two or more cells. The bottom of each cell is levelled and the vegetation is dense. The wetland treats agricultural wastewater using natural processes: solids settle and are filtered; organics are used as food by microorganisms; nutrients and metals are attenuated by plants, microorganisms, and soil; and pathogens are removed with the solids and gradually die with time.

Constructed wetlands usually utilize plant species native to the given area. The plants provide the right conditions for micro-organisms that live in the wetland. Wetland plants only remove a small fraction of the pollutants present in wastewater, most treatment is provided by the numerous bacteria and other micro-organisms that live on the host plants.

A lagoon, pond, or other pre-treatment solids trap is usually used in front of a constructed wetland system to remove heavy and coarse solids. Much of the organic solids that settle out of the wastewater in the lagoon are aerobically or anaerobically digested. Any remaining sludge is removed and either disposed of, composted, or land-applied as fertilizer. The pretreatment lagoon then discharges liquid effluent to the constructed wetland.

The constructed wetland includes one or more wetland cells in series or parallel. Multiple cells improve the effectiveness of the system and provide for flexible operation and maintenance. Construction is simple -- a bulldozer can be used to level the site and build small dikes around the system. PVC pipe is usually used to distribute and collect wastewater and to control water levels in the wetlands. Water levels are normally very shallow, ranging from 3 to 12 inches. Uncontaminated stormwater runoff is routed away from the system or can be stored and used for dilution if needed. A constructed wetland can be designed to either discharge treated wastewater or to have no discharge whatsoever.

This system is especially useful in the Virgin Islands because we have a year-long growing season so that plants and microbes can continually treat the wastewater. The high evapotranspiration rates common to the Virgin Islands are also favorable to this type of system -- a wetland can be designed so that no effluent leaves the wetland, it is all used by the plants. For 150 dairy cows, the estimated required land area for a constructed wetlands system (including pre-treatment) is 1 to 2 acres (U.S. EPA, 1992).

The system should be inspected periodically to detect and correct or manage any potential problems such as short-circuiting of flow, loss of plants, leakage through dikes, and pipe clogging.

Advantages

- low cost construction and operation;
- energy efficient;
- accepts varying waste loads;
- simple operation and maintenance;
- aesthetically pleasing; and attracts wildlife

Limitations

- steep topography;
- shallow topsoil or depth to bedrock;
- limited land space;
- engineers and regulators not yet familiar with technology; and
- potential mosquito production

DESIGN CONSIDERATIONS FOR CONSTRUCTED WETLANDS

This practice is applicable where:

- An overall waste management system has been planned;
- Wastewater generated by agricultural production or processing needs treatment;
- Wastewater is of sufficient volume and duration to keep the constructed wetland moist at all times;
- Wastewater or polluted runoff can be discharged to the constructed wetland at a controlled rate;
- Soil, water and plant resources are adequate to properly establish suitable vegeta tion and to allow for proper management of the constructed wetland; and
- Any effluent from the wetland can be either recycled, land-applied, or discharged in accordance with local (V.I. DPNR) and federal (U.S. EPA and NOAA) regula tions (SCS Caribbean Area, 1993).

Plants selected for use in constructed wetlands should be emergent hydrophytic vegetation suitable for tropical climates and tolerant of high concentrations of nitrogen and other pollutants in animal wastewater. Plants used should be native to the given area. Principal plants include:

- Cattail (*Typha* sp.)
- Bulrush (*Scirpus* sp.)
- Maidencane (*Panicum hemitomon*)
- Rushes (*Juncus* sp.)
- Reeds (*Phragmites* sp.)

Other species that can be used include pickerel weed (*Pontedaria cordata*), arrowhead (*Sagittaria latifolia*), canna lily (*Canna flacida*), elephant ear (*Colocasia esculenta*), blueflag iris (*Iris virginica*), giant cutgrass (*Zizaneopsis miliacea*), and water chestnut (*Eleocharis dulcis*). Free floating plants, such as water hyacinth and duckweed, although proven useful in other systems, should not be used due to the need for harvesting (SCS, Caribbean Area, 1993).

System design should be based on treatment objectives, quality of influent, and realistic performance expectations. Minimum treatment objectives based on effluent concentrations from the wetland are:

- Biological Oxygen Demand (BOD_5) < 15 mg/L
- Total Suspended Solids (TSS) < 30 mg/L
- Ammonia + Ammonium-Nitrogen (NH_3-N + NH_4-N) < 10 mg/L

Constructed wetland size can be determined as a function of influent pollutant concentrations, desired effluent pollutant concentrations, wastewater flow rate within the cells, water temperature, evapotranspiration, and the ratio of the volume of the wetland occupied by water to the volume occupied by plants and water.

Technical assistance for installing constructed wetlands systems is available to farmers and homeowners in the Virgin Islands from the UVI Cooperative Extension Service, the USDA Soil Conservation Service, the Environmental Protection Agency, and private consultants. Financialassistance is available from the Small Business Administration under Section 7(a)(12) - Loan Program for pollution control facilities, and USDA ASCS provides 70% cost-share for earth work and materials for the installation of constructed wetlands. Farmers Home Administration also offers loans to construct agricultural wastewater treatment facilities.

EXAMPLES FROM AROUND THE COUNTRY

The Scott dairy farm in Herando, Mississippi is a 117-head dairy. Wastewater from milking equipment, barn wash water, loafing area runoff, and rainfall flows into an earthen lagoon 5140.8 m^3 (183,600 ft^3, areal extent 0.21 ha or 0.53 acre). Runoff is pumped from the lagoon to a holding tank, from which constant wastewater flow moves to three parallel 134.4m^3 (4800 ft^3, areal 1600 ft^2 or 148.8 m^2) wetland cells for treatment. Giant bulrushes (*Scirpus validus*) were planted in the wetland cells at 1-foot intervals. Each cell processes 51 ft^3/day of wastewater. Eighteen water quality indicators are monitored bi-weekly. A fourth cell was built two months after installation to further treat outflow from cell 1. Adding a cell in series halved the amount of contaminants in the effluent (TSS and phosphorus). The wetlands system is very effective in removing the primary targets of the project: Ammonia (91%) and total coliform (96%).

The Auburn University AES, Alabama, has a 500-animal farrowing and finishing swine operation. using a constructed wetlands treatment system. Waste is routed to a two-cell-in-series lagoon system. Wastewater discharges from the lagoons into a mixing pond that also receives water from a farm pond located upstream. Effluent then flows from the mixing pond into five pairs of cells planted with marsh vegetation, then into a wet meadow for final polishing. The treatment area in the cells is 3600 m^2 with an additional 2100 m^2 in wet meadow. System piping provides for variable wastewater application rates and water level control within each cell. The cells were initially planted with cattail (*Typha latifolia*), soft-stem bulrush (*Scirpus Validus*), giant cutgrass (*Zizaniopsis miliacea*), maidencane (*Panicum hemitonom*), common reed (*Phragmites australis*), and water chestnut (*Eleocharis dulcis*). However, other species quickly invaded. Four groundwater wells were installed near the wetlands along with 16 lysimeters installed in 4 of the wetland cells for monitoring.

The 500-animal swine operation is estimated to produce 90 kg BOD_5/day, reduced to 36 kg BOD_5/day (60%) in the final lagoon discharge. Minimum treatment area for 36 kg BOD_5/day at 150 m^2/kg BOD_5/day is 5400 m^2. The total treatment area of the wetlands system and finishing meadow is 5700 m^2 or 158 m^2/kg BOD_5/day.

Results of monitoring show that treatment performance of the wetland is not affected by type of vegetation. Pollutant removal rates are consistent regardless of loading rate. The replicate wetland tier produced significant reductions of TKN, NH_3-N, TP, and fecal streptococci. The wet meadow significantly enhanced removal of TSS, BOD_5 and fecal coliform. Total pollutant removal for the entire system is 90.4% BOD_5, 91.4% TSS, 99.4% fecal coliform, 98.4% fecal streptococci, 75.9% total P, 91.4% TKN, and 93.6% NH_3-N.

The Lajas, Puerto Rico Experiment Station will be conducting a study involving the use of constructed wetlands for treatment of hog waste for a 100-animal farrowing and finishing operation. Construction of the facility is nearly complete. The waste treatment system will consist of a settling pond with effluent routed to six wetland cells with a total area of 600 m^2. Four different wetland species will be planted, including sedges (*Cyperus* sp.), cattails (*Typha* sp.), water chestnut (*Eleocharis dulcis*), and elephant ear (*Colocasia esculenta*). The system is designed to remove nitrogen and phosphorus to levels that meet Commonwealth of Puerto Rico water quality standards.

CONCLUSION -- VIABILITY IN THE VIRGIN ISLANDS

Constructed wetlands offer great potential for treating animal waste in the Virgin Islands. Our year-long growing season and high evapotranspiration rates can greatly enhance the effectiveness of wetland plants and microbes in filtering out, digesting and/or adsorbing pollutants and vastly reducing wastewater volumes. It is even possible to design a system that can completely evapotranspirate the wastewater so that there is no discharge. However, one drawback to this system is the scarcity of suitable land and its cost.

Constructed wetlands are already being successfully used across the U.S. and in other countries.

Nutrients, organic materials, and pathogens can be successfully removed with this "passive" system. This "natural" technology has many advantages both in the Virgin Islands and across the Caribbean, and its advantages far outweigh any disadvantages.

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VESICULAR ARBUSCULAR *MYCORRHIZAE* IN THE CARIBBEAN - PAST, PRESENT AND FUTURE

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ABSTRACT

Mycorrhizae formed between plant roots and zygomycetous fungi are ubiquitous and can improve the productivity of most crop plants. The use of effective vesicular-arbuscular (VA) mycorrhizal fungi could enable the development of sustainable agricultural systems with reduced input of high cost fertilizers. This paper reviews the limited knowledge of the VA mycorrhizal fungal species present in Caribbean agriculture and highlights the need to determine which species/strains are present in Caribbean soils and also their effectiveness. The potential of surrogate plant transformation via genetic engineering of VA mycorrhizal fungi is considered and the possible consequences of releasing genetically modified VA mycorrhizal fungi are discussed.

INTRODUCTION

Vesicular-arbuscular (VA) mycorrhizal fungi are obligate endophytes that generally lack specificity for host plants. They are found in almost all ecosystems, forming mutualistic associations with members of a very wide range of plant families. These associations, VA mycorrhizae, are found predominantly in angiosperms but their presence in bryophytes, pteridophytes and gymnosperms have also been reported. Among the angiosperms, VA mycorrhizae may be absent in members of the Brassicaceae, Chenopodiaceae, and Cyperaceae (Hirrel *et al.*, 1978) and in ecosystems where ectomycorrhizae and/or ericoid mycorrhizae are prevalent. It is postulated that the VA mycorrhizal association occurred early in plant evolution and co-evolution of plants and VA mycorrhizal fungi followed (Nicolson, 1975).

VA mycorrhizal fungi are Zygomycetes and are classified into six genera, *Acaulospora, Entrophospora, Gigaspora, Glomus, Sclerocystis* and *Scutellospora* (Schenck and Perez, 1988; Morton and Benny, 1990). This classification of VA mycorrhizal fungi is based on characteristics of the asexual spores, such as their gross morphology, ontogeny and spore wall murographs, as no sexual spores of these fungi have been identified conclusively (Siquiera *et al.*, 1985; Morton and Benny, 1990).

In the soil, fungal colonisation starts when extraradical hyphae or germtubes come in contact with host roots. The fungal hyphae then differentiate and appressoria are produced followed by penetration into the epidermal and subepidermal layers of the root. Extensive inter- and intracellular hyphal growth follows and eventually arbuscules are formed by invagination of root cortical cells. Intraradical vesicles may be produced depending on the genera of VA mycorrhizal fungi involved in the symbiosis (intraradical vesicles are not produced by *Scutellospora* and *Gigaspora*) and extraradical hyphae grow into the soil to continue the process. The same root can be colonised several times by extraradical hyphae. When suitable environmental conditions are available the fungus sporulates, the asexual spores are usually borne on the extraradical hyphae. *Gl. intraradix* has the unique feature of producing spores within host roots.

The positive affect of VA mycorrhiza formation on the uptake of minerals by the host plant, especially phosphorus in P-limited soils, has been reported repeatedly. The physiological effects on plants as a result of VA mycorrhiza formation are similar to those of phosphorus additions to soils low in this mineral. Conversely, soils with high P levels do not promote mycorrhizal development

(Menge, 1978; de Miranda *et al.*, 1989). It is not uncommon for P depletion zones to develop around roots especially in soils with low concentrations. VA mycorrhizal fungi extend the surface area of the roots thereby enabling the mycorrhizal root system to explore a greater volume of soil for phosphorus, usually beyond the depletion zones. The smaller diameters of the hyphae also allow the fungus to explore smaller pore spaces than roots and roots hairs. Some studies have suggested that VA mycorrhizal fungi can alter unusable forms of phosphorus (i.e. adsorbed and organic phosphates) and make them available to the plant (Brundrett, 1990).

VA mycorrhizal fungi exert other effects on the physiology of colonised plants. VA mycorrhizae affect the water relations of plants (Allen *et al.*, 1981), the carbon economy, and may influence plant community structure by regulating nutrients and water among plants (Allen and Allen, 1986). VA mycorrhizae also enhance plant growth (Smith, 1980; Nielsen, 1990), plant disease resistance (Morandi *et al.*, 1984; Caron, 1989; Feldmann *et al.*, 1989), and plant reproduction (Koide *et al.*, 1988) and reduce competition between large plants and seedlings (Eissenstat and Newman, 1990). VA mycorrhizal fungi enhance plant micronutrient uptake when low levels of these micronutrients are present in the soil and provide protection to the plant when these micronutrients are available in phytotoxic amounts (Persad-Chinnery and Chinnery, 1994).

A better understanding of VA mycorrhizae and the VA mycorrhizal fungus lifecycle could hasten their eventual exploitation in agroecosystems. In recent years, as a result of agricutural diversification and intensification, fertilizer use has been increased. Although Barbados spent about US$2 million dollars per year between 1982 and 1991 on imported fertilizers, the quantity has increased (Barbados Customs Statistics). Usually more than half of an applied phosphorus fertilizer is unavailable to the plant. In order to compensate for this loss, phosphorus fertilizer is added in amounts greater than necessary for plant growth. Since VA mycorrhizae can extract nutrients more efficiently from the soil than non-mycorrhizal roots, it is thought that VA mycorrhizal fungi could be used as "biotic fertilizers" and that VA mycorrhizal fungi may substitute for a substantial part of fertilizer input in the field. For the crops they were working with, Medina *et al.* (1990) found that field inoculations with *Gl. intraradix* and *Gl. etunicatum* resulted in a minimum of 30% decrease in the amount of phosphorus fertilizer (40 kg ha^{-1}) required for maximum yields. It is predicted that marginal soils low in nutrients, for example soils slashed and burnt, that, due to the high fertilizer input required, are too expensive to cultivate, could be used for agriculture once the soil is inoculated with a suitable species of VA mycorrhizal fungus.

Since VA mycorrhizal fungi occur in association with most cropped plants, their potential exploitation in agriculture is significant. Thus, an immediate, and coordinated, effort should be made to identify the species of VA mycorrhizal fungi present in Caribbean soils and to evaluate the effectiveness of the various species/strains present with each of our crop plants. This information is necessary before large scale field inoculation can be considered. Phytosanitary considerations may limit use to indigenous species.

Under field conditions successful inoculation of soil with VA mycorrhizal fungi will depend on several factors:

(1) the native VA mycorrhizal fungal species present,
(2) the VA mycorrhizal fungal species introduced and its competitive advantage over the native species,
(3) the type of inoculum, that is whether spores or root pieces are used,
(4) interplant connection that may result in donors and recipients of nutrients,
(5) grazing, since fungi are a food source for many soil organisms,
(6) root longevity,
(7) the seasonality of spores, and
(8) the interaction between VA mycorrhizal fungi and other soil microorganisms.

Traditional agronomic practices must also be examined to determine their effects on VA mycorrhizal fungi (Persad-Chinnery *et al.*, 1992). For example, since tilling tends to create environments more conducive to the growth of bacteria, untilled soils support greater mycorrhizal fungal colonisation of roots and sporulation (Hendrix *et al.*, 1986). Pesticides and inorganic fertilizers may also have deleterious effects on populations of beneficial soil organisms including VA mycorrhizal fungi and inter-cropping may be better than monoculte since VA mycorrhizal fungal diversity tends to increase with host diversity (Rabatin and Stinner, 1989).

Since all the factors stated above for successful field application need to be evaluated for each soil type, it is likely that evaluation would require a long time before the potential of field inoculation is fully realised. However, there are aspects of Caribbean agriculture where VA mycorrhizal fungi can be utilised almost immediately to enhance plant growth and survival. For example, the survival rate of tissue cultured plants during the hardening and outgrowing process can be increased significantly if the potting soil is inoculated with the appropriate species of VA mycorrhizal fungus. Another area of immediate utilisation is in plant/tree nurseries. VA mycorrhizal fungi have been shown to increase the survival rate of transplanted seedlings. Michelini and Nemec (1988) used two *Glomus* spp. and an unidenified local inoculum, in a Barbadian nursery, to improve the survival of transplanted citrus.

VA MYCORRHIZAE IN THE CARIBBEAN - PAST

Several studies conducted in the tropics have shown that VA mycorrhizal fungi are prevalent in tropical soils and form mycorrhizae with plants of agricultural importance. A selection of of these studies, restricted to those in which the fungal endophyte(s) was identified, is presented in Table 1.

Based on a recent search of the Dialog(R) databases and our own extensive mycorrhizal literature collections, knowledge of VA mycorrhizae in the Caribbean is limited. In 1968, Kreisel published a survey of the fungus flora of Cuba, however, there was no documentation of VA mycorrhizal fungi. Only species involved in the more noticeable ectomycorrhizal type of mycorrhiza were included. The first reports on VA mycorrhizae in the Caribbean were those of Pyke (1935), who reported the presence of mycorrhizae in *Theobroma cacoa*, and Laycock (1945), who also reported the benefits of mycorrhizae in cocoa. The first study to report the prevalence of VA mycorrhizae in Caribbean soils and the positive effect of VA mycorrhizae on plant growth was conducted by Johnston (1949). This study was conducted in two parts. In the first, plants representative of the flora of Trinidad were collected from various habitats and classified as weeds, secondary bush (species regenerating waste land), forest trees, orchard savannah species and crop plant species. About 87% of the crop plants and savannah species, about 77% of weeds and 79% secondary bush were VA mycorrhizal. Interestingly, 100% of the forest trees examined were VA mycorrhizal and colonisation was well established. In the other plant categories colonization was moderately established In the second part of the study the effect of different soil types on colonisation and growth of sea island cotton (*Gossypium barbadense* L.) was investigated. It was found that root colonisation by VA mycorrhizal fungi was greatest, about 90%, and plant growth was improved in nutrient poor soil, low in organic matter, nitrogen and deficient in phosphorus and potasium. Improving the soil fertility by the addition of pen manure did not alter the level of colonisation or the benefits. However, when the soil was amended with inorganic fertilisers the percentage VA mycorrhizal colonisation was reduced by just over 20%. No species identifications of the VA mycorrhizal fungi observed were made. This lack of identifications in older papers on VA mycorrhizae is not uncommon since, as stated above, identifications are made on spore characteristics and spores are at times difficult to obtain.

A study was conducted by Chinnery *et al.*, (1987) to determine the influence of VA mycorrhizal fungi on the growth of 16 clones of sugarcane (*Saccharum* hybrids) in Barbados. It was noticed that sugarcane yields, in Barbados, were maintained despite continuous growth on the same fields without the addition of phosphorus fertilisers. Roots were collected and analysed in December, January

and February. VA mycorrhizal colonisation of 70-75% was recorded in December and February, and a lower colonisation rate of 56% was measured in January. These high levels of colonisation are thought to contribute to consistent sugarcane yields in Barbados. It was postulated that the reduction in colonisation in January may have been due to the change in soil moisture that is characteristic of the start of the dry season and that the increased colonisation in February may have been due to the dominance of another species of VA mycorrhizal fungi, possibly one more tolerant of dryness. No species identifications were attempted in this study.

The influence VA mycorrhizal fungi have on the growth of mycorrhizal roots was investigated in two independent studies (Inniss, 1989; Persad-Chinnery, unpublished). Both found that VA mycorrhizal fungi affect meristematic cell division in the roots of host plants such that the root mitotic indices of VA mycorrhizal plants were lower than non-mycorrizal plants.

Michelini *et al.* (1989) examined the effect of paclobutrazol on the VA mycorrhizae of alemow (*Citrus macrophylla* Wester) in Barbados. Paclobutrazol, that has limited fungicidal properties and is a plant growth regulator, was added at concentrations of 0.03, 0.06, 0.125, 0.5 and 1.0g active ingredient to soil in containers planted with alemow. Mycorrhizal colonisation by *Glomus* spp. was greatest at 1.0 g paclobutrazol, possibly due to greater mycorrhizal dependence of the plant as its root became stunted as a result of treatment. Paclobutrazol did not appear to have any fungicidal effects on these mycorrhizal species.

In Jamaica, species of *Gl. pallidium*, *Gl. aggregatum*, and *S. microcarpa* were selectively used with species of *Rhizobium* to determine the best combination for optimum growth of cowpea (*Vigna unguiculata* L.) planted in Jamaican soils (Ames *et al.*, 1991). Their study concluded that VA mycorrhizal fungi and *Rhizobium* functioned synergistically to improve plant growth when compared to either alone. Also in Jamaica, Coates-Beckford and Pereira (1992) examined the microorganisms associated with breadfruit (*Artocarpus altilis*) roots in an attempt to identify the causative agent of "decline", characterised by premature fruit drop, leaf chlorosis, flower abscission and branch dieback. *Gl. tenuis* was found associated with roots of both healthy plants and those exhibiting decline.

Persad-Chinnery *et al.* (1992) developed a consistent and reliable method of *in vitro* spore germination for spores of *Gigaspora* using a commercial preparation of cellulase. These spores were recalcitrant to germination by standard methods.

In another study by Michelini *et al.* (1993), citrus roots were examined in Barbados, Dominica, Grenada and St. Lucia. They were able to show that environmental factors such as rainfall, pH, altitude, organic matter and micronutrients influenced the level of VA mycorrhizal colonisation. The healthiest plants were the most highly colonised. Most of the VA mycorrhizal fungi identified from soils around the citrus roots were *Glomus* spp. A few were *Sclerocystis*, *Gigaspora* and *Scutellospora*.

Extensive research has been conducted on the sand dunes on the east coast of Barbados. *Gigaspora margarita* and *Scutellospora gregaria* have been identified as the two species present in the sand dunes. L.D. Waterman (unpublished) has not been able to find any seasonality trends based on spore abundance in the sand dunes after several years of monitoring. A study conducted by Kirton (1993) in the same area showed that spore abunduance was greatest in the higher, older and vegetated parts of the sand dunes. The intensity of infection in this region of the dune was much lower than the areas that were newer and vegetated. The findings of this study may be incorporated into strategies to conserve and stabilise the dunes.

VA MYCORRHIZAE IN THE CARIBBEAN - PRESENT

Although research on VA mycorrhizae in the Caribbean is limited, a significant portion of the published literature originate from U.W.I., Cave Hill and research in this area is ongoing. Presently, L.D. Waterman (unpublished) is developing species specific primers that could be used in PCR (polymerase chain reaction) to identify the species of VA mycorrhizal fungus present in a

mycorrhiza or in a mixed population of fungi. The usefulness of this development goes beyond the Caribbean. The present method of identification is based on spore characteristics and it can take several months before spores are available. This novel method will enable the researcher to know almost immediately the genus and species of VA mycorrhizal fungus involved in the mycorrhiza.

Studies on the nuclear cytology during the precolonisation and colonisation phases of the VA mycorrhizal fungal lifecycle, on drug resistance of *Gigaspora* spores and on the construction of a VA mycorrhizal fungal genomic library are continuing (Persad-Chinnery, unpublished). These studies are aimed at developing a transformation system for *Gigaspora* that would enable genetic manipulation of the VA mycorrhiza for improved effectiveness.

Another active area of research is to determine the influence VA mycorrhizal colonisation may have on alleviating the symptoms of bunchy top disease in Papaya (A. Waterman, unpublished).

VA MYCORRHIZAE IN THE CARIBBEAN - FUTURE

The future of VA mycorrhizal research in the Caribbean is likely to progress from two aspects. Firstly, VA mycorrhizal fungi could become incorporated into the tissue culture and nursery operations, as the relevent persons realise the potential of these fungi. Secondly, there is likely to be greater attempts at manipulating the VA mycorrhizal association through genetic engineering to enhance effectiveness. Genetic engineering refers to the use of laboratory or industrial techniques to modify an organism's genetic material. One possible method of manipulating VA mycorrhizal fungi is via transformation. This method normally involves introducing DNA encoding desirable genes into the organism by protoplast isolation and regeneration, biolistics or electroporation This introduced DNA may then become incorporated into the fungus' DNA and function as fungal DNA.

As there are no known sexual stages for VA mycorrhizal fungi and since they are obligate symbionts the development of a transformation system could enable genetic studies such as the organization of their eukaryotic genome, the structure of mycorrhizal genes and the regulation of different molecular processes, to be studied. All of this information is necessary to fully comprehend the VA mycorrhizal association in the soil.

The development of a transformation system for *Gigaspora*, currently being pursued at U.W.I., Barbados, will allow the introduction of genes from both plant and microbial sources to be introduced into the fungus that may lead to a better understanding of the VA mycorrhizal symbiosis at a molecular level. There are several candidate genes that could be introduced into the fungus, should a transformation system be developed. Firstly, genes encoding the production of phytohormones that stimulate root and mycorrhizal development. Harley and Smith (1983) reported that IAA (indoleacetic acid) promotes root growth and enhances mycorrhizal symbiosis. The introduction of the IAA gene into VA mycorrhizal fungi may lead to further understanding the role of phytohormones in mycorrhizal formation and function.

Secondly, genes for substances repellent to soil insects or nematodes could be introduced into VA mycorrhizal fungi. These transformed fungi could be used to reduce the cost of pesticide input in agriculture. Similarly, genes for more efficient absorption and translocation of nutrients from the soil to the plant would greatly increase the importance of VA mycorrhizal fungi as biofertilisers. For example, genes encoding enzymes such as phosphatase or nitrate reductase, could influence nutrient availability or alleviate various edaphic stress factors. Additional genes of agricultural importance are those encoding for metabolites that foster plant osmotolerance, plant disease resistance and plant resistance to pesticides. The advantage of introducing these genes into the fungus is that the plants are likely to benefit without being subjected to bioengineering. Trangenic VA mycorrhizal fungal inocula may effectively substitute for fertilizers and/or pesticide inputs in agriculture. The ultimate goal is to develop improved fungal strains for use as inocula in agriculture.

Another advantage of introducing genes into VA mycorrhizal fungi is that genes for root related functions can be restricted to expression by the fungus. Thus the plant benefits from the gene

product without the gene being present in the plant genome and the plant is free from any genetic manipulations. This is obviously a more desirable situation since in many parts of the world genetic manipulation of food plants is viewed with suspicion by most consumers.

There seem to be an inexhaustible scope for research should a transformation system for VA mycorrhizal fungi develop. However, in considering strategies to improve symbiosis it will be important to avoid non-target effects that could disrupt the balance among rhizosphere components. The general intention of the research should be to optimise the plant-fungus symbiosis through genetic manipulation of the fungal component without impairment of the components of the rhizosphere ecology that may be supportive to that symbiosis.

The process of genetic engineering is similar to the activities of traditional plant breeders and, as such, should offer no additonal risks. However, since the techniques used in molecular biology are not natural, genetically engineered organisms are viewed as things to fear. The release of transgenic VA mycorrhizal fungi in the field could pose two potential concerns. Firstly, the introduced gene, although providing a benefit to a particular crop plant, could be passed on to other plants, possibly weeds since the host range of these fungi is diverse. Secondly, the transgenic VA mycorrhizal fungus may behave as an invasive species, possibly leading to the reduction or extinction of native species of VA mycorrhizal fungi. Both concerns can only be evaluated to determine the risks when transgenic VA mycorrhizal inoculum can be taken into the field for regulated testing following the proper procedure defined by an objective governing body. Possibly the best course of action to users of this technology is to evaluate the risks and the benefits involved. As with all modern inventions, if the benefits are greater than the risks involved then the technology can be classified as useful. If improved plant growth results from transgenic VA mycorrhizal fungal inoculum, such that the plant product of economic importance is increased significantly, then the threat of improving the growth of weeds or reducing native populations of VA mycorrhizal fungi become acceptable risks.

CONCLUSION

At least 80% of the angiosperms that inhabit the earth are VA mycorrhizal, implying that many plants are always VA mycorrhizal, however these fungi tend to be considered as part of the root anatomy and not as separate entities and have received little attention in the Caribbean. Among plant physiologists these fungi and other microbial mutualists are seldom considered as contributors to the nutritional status of the plant. The literature published on VA mycorrhizal fungi show that these organisms can greatly improve plant health. The VA mycorrhizal association is too prevalent to be ignored and sustainable utilisation should be the goal of all plant growers. Sustainable agriculture which is as much a process as an end point can incorporate VA mycorrhizal fungi as an important component of the process. Beyond the Caribbean region there are examples of plant nurseries and tissue culture laboratories that utilise VA mycorrhizal fungi without any adverse effects when the plants are introduced into the field. It is important that we are aware of the species present in Caribbean soils if field inoculation is to achieve any success in the future. Interaction between these fungi and particular crop plants also need to be evaluated for this purpose. This information will also prove useful in evaluating the risks of using transgenic VA mycorrhizal fungi should they become a reality in the future.

Table 1: Reported associations between agricultural crops and VA mycorrhizal fungi in the tropics.

CROP SPECIES	VA MYCORRHIZAL SPECIES	REFERENCES
Chilli (*Capsicum annuum*)	*G. calospora* *G. margarita* *Gl. fasiculatum* *Gl. intraradix*	Hari Babu *et al.* (1988)
Corn (*Zea mays*)	*A. caulospora* *Glomus* spp. *Scutellospora* spp.	Berch (1989)
Onion (*Allium cepa*)	*Gl. fasciculatum* *Gl. mosseae*	Alexander *et al.* (1989) Afek *et al.*, (1990)
Bean (*Phaseolus vulgaris*)	*Gl. fasciculatum*	Alexander *et al.* (1989)
Tomato (*Lycopersicon esculentum*)	*Gl. fasciculatum* *Gl. etunicatum* *Gl. intraradix*	Alexander *et al.* (1989) Bryla & Koide (1990) Caron *et al.* (1985)
Cotton (*Gossypium hirsutum*)	*Gl. deserticola*	Afek *et al.*, (1990)
Citrange (*Poncirus x Citrus*)	*Gl. intraradix*	Johnson & Hummel (1985)
Sour orange (*Citrus aurantium*)	*Gl. intraradix*	Graham & Syvertsen (1989) Nemec, (1992)
Sweet orange (*Citrus sinensis*)	*Gl. intraradix*	Graham & Syvertsen (1989)
Avocado (*Persea americana*)	*Sclerocystis sinuosa* *Gl. macrocarpum* *Gl. fasciculatum* *Acaulospora* spp. *Glomus* spp.	Haas & Menge (1990)
Sweet potato (*Ipomoea batatas*)	*Gl. clarum*	Paula *et al.*, (1992)
Coffee (*Coffea arabica* var. Catturra)	*A. longula* *A. myriocarpa* *E. columbiana* *Scutellospora heterogama* *Gl. fasciculatum* *Gl. manihitis* *Gl. occultum*	Siverding & Toro (1990)

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GOOD LABORATORY PRACTICES FOR IR-4 FOOD USE PROJECTS IN FLORIDA AND PUERTO RICO

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ABSTRACT

The amended Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) Good Laboratory Practice (GLP) Standards (40 CFR Part 160) regulations became effective on October 16, 1989. The revisions require all studies submitted to the Environmental Protection Agency (EPA) in support of pesticide registration to be in compliance with the regulations. Tolerances and registrations of pesticides under FIFRA require high standards of data quality and integrity. To assure this, the GLP standards delineate practices and procedures that must be followed during data collection. Residue data are required for obtaining residue tolerances for minor use pesticides in or on food and feed crops. Field researchers from Florida and Puerto Rico, cooperating in the Southern Region of the Interregional Research Project No. 4 (IR-4 Project) minor use pesticide program, have conducted field trials for the magnitude of pesticide residues on minor use crops. From 1989 to 1994, 98 IR-4 supported field trials were conducted under GLPs on tropical crops in Florida and Puerto Rico.

INTRODUCTION

The IR-4 program was established in 1963 and in cooperation with farmers, agriculture scientists (federal, state, and industry), and extension personnel perform the research needed, prepares, and submits petitions to the EPA for the registration or requests for tolerances (legal maximum residue concentration of a pesticide chemical allowed on food or feed), or exemptions of pest control materials on minor crops. Minor crops include food crops, ornamentals and landscape plants, commercially grown flowers, shade trees, and turfgrass. While the total acreage of minor crops is less than eight million acres in the U.S., the combined value of these crops is about $24 billion annually or 40% of all agricultural crop sales (USDA, 1991). Minor uses that involve limited treatments to large acreage crops are also considered. IR-4 receives federal funds from both USDA-Cooperative State Research Service (CSRS) and USDA-Agricultural Research Service (ARS). Participating scientists, consisting mainly of state and federal agricultural researchers, state extension personnel, commodity grower groups, and sometimes private consultants carry out field trials to develop crop safety dataand collect residue samples. These samples are analyzed in IR-4 regional and satellite laboratories at state universities, agricultural experiment stations, and federal analytical laboratories.

The program is coordinated from a headquarters at Rutgers University and the New Jersey Agricultural Experiment Station in New Brunswick, NJ, regional, and ARS laboratories. There are liaison representatives in each state and territory. Crop producers, the agrichemical industry, and the EPA participate in the program. The scope of IR-4 is limited to field testing (effectiveness against the pest(s) and crop safety) plus residue analyses. Core data requirements, such as chemistry, toxicology, and environmental fate, have been completed by the agrichemical registrant. IR-4 proceeds with research after obtaining written approval from the registrant.

APPLICATION OF GLP STANDARDS TO FIELD STUDIES

As the cost of meeting regulatory requirements increased, pesticide registrants concentrated

their registration efforts in areas where they could obtain sufficient economic returns to justify their research and development costs. This resulted in greater registrations of pesticides for the large acreage crops and a lack of availability and variety of pesticides for use on minor crops (IR-4 project statement, 1994). The situation became more critical by the amendments to FIFRA in 1988 (FIFRA, 1988), which require a significant acceleration of the reregistration process for previously registered pesticides.

The purpose of the IR-4 project is to ensure that producers of minor crops have an adequate supply of pest control products (both traditional pesticides and biopesticides). To achieve its objectives, all research (field and laboratory), conducted by scientists cooperating with the IR-4 program, which is to be used in support of a tolerance and registration must follow GLP requirements mandated by the EPA.

The EPA is requiring compliance with the amended FIFRA GLP standards, which were finalized on October 16, 1989, and the Toxic Substances Control Act (TSCA, 1989). Amendment of the regulations expanded the GLP requirements to include field testing, environmental effects testing, and environmental fate testing. They specify minimum practices and procedures that must be followed to ensure the quality and integrity of data submitted to the EPA in support of a research or marketing permit for a pesticide product. Under the GLP regulations studies should be conducted according to scientifically sound protocols with detailed attention to quality control. These studies must be done as written in the protocol, and theresults accurately reported. Townsend (1992) stated that the most compelling reason the EPA applied the GLP standard to the agrichemical industry was the result of a new and subtle type of public activism that demands accountability, and they were inevitable since compliance is a public demand.

The EPA originally published the FIFRA GLP standards in the Federal Register of November 29, 1983 (40 CFR Part 160). Under these regulations, the EPA only required GLP compliance under FIFRA for health effects testing. At the same time, the EPA published GLP standards applicable to testing required under TSCA (40 CFR Part 792). In the preamble to the publication of the 1989 FIFRA GLP final rule, it was stated that these regulations were promulgated in response to investigations by the EPA and the Food and Drug Administration (FDA) in the mid-1970's which revealed that some studies submitted to the Agencies had not been conducted in accordance with acceptable laboratory practices. Some examples included that they did not adhere to specified protocols, were conducted by underqualified personnel and supervisors, were not adequately monitored by study sponsors, and results were selectively reported, underreported, or fraudulently reported.

IR-4 FOOD USE PROJECTS IN FLORIDA AND PUERTO RICO

IR-4 has established procedures for study conduct to comply with the GLPs. Each study has an approved protocol and the magnitude of the residue in or on the commodity must be determined according to the EPA's Pesticide Assessment Guidelines, Subdivision O (Schmitt, 1982), and following the EPA's data requirements and GLP standards. Subdivision O describes protocols that may be used to perform food, feed, or tobacco residue testing to support the registration of pesticides under the Federal Food, Drug, and Cosmetic Act (FFDCA) and FIFRA. These data are used to estimate the exposure of the general population to residues in food and to establish and enforce tolerances for pesticide residues in food and feed.

40 CFR Part 160.120(a) states that the approved written protocol must "clearly indicate the objectives and all methods for the conduct of the study." The IR-4 protocols are used for planning and executing studies, and consist of field trials and laboratory analyses. They include the establishment and maintenance of test plots; procurement, storage, and application of test chemicals; collection, storage, and shipment of samples for analysis; laboratory sample storage and preparation; acquisition of reference standards; analytical methodology; disposition of samples; documentation and recording keeping; reporting and archiving of data.

Each IR-4 field/laboratory researcher has a set of Standard Operating Procedures (SOPs) which are required under GLP regulations. These are written procedures for routine operations that trained personnel must follow to ensure the quality, integrity, and consistency of the work performed during a study. Together with the protocol they assure that studies are conducted with good planning, proper execution, and complete documentation. SOPs are written for all technical functions and for all other functions required by the GLP regulations. They aid in training, eliminate some supervision, and add consistency and uniformity to data generation. The GLP regulations require "management" to approve all SOPs and be satisfied that these procedures ensure the quality and integrity of the data generated during a study. The study director must ensure that the SOPs are followed or deviations from the SOPs are properly documented.

Testing facilities are mandated to establish a quality assurance unit (QAU) which has the responsibility for monitoring each study for conformance with the regulations. Commitment of management is necessary in implementing a successful GLP program, and the IR-4 technical committee has provided resources for maintaining a QA program. The QAU is defined in 40 CFR Part 160.3, as "any person or organizational element, except the study director, designated by testing facility management to perform the duties relating to quality assurance of the studies." IR-4 has established a QAU, consisting of a QA officer at headquarters, regional QA officers, laboratory QA officers, and other QA personnel as required. Members of the QAU are responsible for educating and training the field and laboratory personnel performing IR-4 trials on the GLP standards. They also conduct annual facilities inspections at all IR-4 test locations, inspect critical phases of each study at intervals adequate to ensure the integrity of the study, review the final report to assure that it accurately reflects the raw data of the study and prepare a signed statement noting dates the inspections and findings were reported to management and the study director (Operational Handbook of IR-4, 1993). All other requirements under 40 CFR Part 160 are monitored to ascertain data integrity.

Florida and Puerto Rico are within the southern region of IR-4. Due to the low acreage used on tropical crops, and few incentives for chemical companies to register pesticides for minor crops, there is a lack of availability and variety of pesticides for use on these crops. Growers may face the loss of many needed pesticide uses without the assistance of IR-4, which is the only publicly supported research program in the U.S. created to clear and maintain pest management agents for minor uses (IR-4 Project Statement, 1994). IR-4's contribution to clear pest control agents is important fortropical crops, and the program has generated and is developing data for residue trials in these areas. The following is a list of field trials, for tropical crops, conducted in Florida and Puerto Rico since the GLP regulations have been in effect.

IR-4 SUPPORTED FIELD TRIALS CARRIED OUT ON TROPICAL CROPS ACCORDING TO GLP's IN FLORIDA AND PUERTO RICO 1989-1994

	Crop	Pesticide
Fungicides	Guava	Ferbam
	Mango	Chlorothalonil
	Papaya	Chlorothalonil, Metalaxyl
	Sugar Apple	Metalaxyl
	Nonbell Pepper	Triadimefon
Insecticides	Atemoya	Chlorpyrifos, Malathion
	Avocado	Hexakis, Permethrin
	Mango	Esfenvalerate, Malathion
	Papaya	Malathion
	Passion Fruit	Esfenvalerate, Malathion
	Pineapple	Esfenvalerate, Malathion
	Sapote, Mamey	Carbaryl, Malathion
		Methidathion
	Coffee	Carbaryl, Chlorpyrifos,
		Cyhalothrin, Fluvalinate
	Pigeon Pea	Esfenvalerate
Herbicides	Arracacha	Ametryn
	Cassava	Ametryn, Glyphosate
		Sethoxydim
	Tanier	Ametryn, Fluazifop
		Paraquat, Sethoxydim
	Yam	Ametryn, Fluazifop
		Glyphosate, Sethoxydim
	Banana	Oxyfluorfen
	Pineapple	Fluazifop, Quizalofop
	Calabasa	Clomazone, Oxyfluorfen
		Paraquat
	Coffee	Fluazifop, Quizalofop
	Pigeon Pea	Fluazifop, Glyphosate
	Pepper Nonbell	Clomazone, Fluazifop
		Oxyfluorfen

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STUDIES TO IMPROVE GINGER (*ZINGIBER OFFICINALE* ROSCOE) PRODUCTIVITY AND QUALITY

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ABSTRACT

Poor quality and low productivity of ginger rhizomes made the product uncompetitive on the extra-regional market. This study tested the components that could produce rhizomes of similar quality to the Hawaiian grade. Three field experiments were carried out to evaluate fertilizer formulations, fertilizer rates with organic manures and system of cultivation, and system of cultivation and plant density. Organic manure increased overall yield by 25% and exportable grade ginger by 500%. Closer intra-row spacing produced higher yields in both systems of cultivation. Furrow cultivation maximized total rhizome yield and exportable grade ginger with a 50% reduction in fertilizer requirement of 500 kg. ha^{-1}). Furrow cultivation improved the exportable grade yield of ginger but not overall yield. The addition of phosphate to the 15-08-24 NPK did not improve yields. A combined technology of 25 cm intra row spacing, organic manure, furrow cultivation and NPK fertilizer (15-08-24) at 500 kg. ha^{-1} was compared to the existing technology on 2000 m^2 plots. Exportable grade ginger increased by 300%, and cost of production fell from EC $1.31 kg to EC 0.57kg^{-1}$ (US $1.00 = EC $2.70).

INTRODUCTION

Ginger was identified in 1991 by the Agricultural Diversification Unit (ADCU) as a suitable candidate in the diversification process, is uncompetitive on the extra-regional market due to the generally poor quality of rhizomes (length and thickness), unreliable supplies and the high farm gate prices (OECS/ADCU, 1992).

Medlicott (1990) described the quality requirements of ginger rhizomes of the extra regional market as a minimum length and thickness of 20 cm and 3 cm respectively and a hand weight of not less than 200 g. Ginger of this standard received premium prices on the extra regional market where the prices are set by Hawaiian grade ginger.

The existing technology in St Vincent is planting in flat plowed lands with a spacing of 0.36 m^2 per plant. This cultivation method produces yields of 8 to 12 t. ha^{-1}. Stephenson (1989) reported that ginger quality similar to the Hawaiian grade ginger was produced in Dominica through furrow cultivation combined with organic manure application (10 t. ha^{-1}) and high rates of fertilizer (1.2 t. ha^{-1} of a 24-24-30 NPK).

This study focused on evaluating the effectiveness of organic manure addition, fertilizer formulation and rates, system of cultivation and plant density on productivity, quality and cost of production. This work was done during 1989 to 1992 at three sites in St Vincent.

MATERIAL AND METHODS

Experiment 1

Evaluation of the effect of different fertilizer formulations on exportable grade ginger.

Four fertilizer formulations 15-08-21 (Banana), 18-18-05 (ORD), 21-00-00 (Sulphate of Ammonia) and 15-18-21 (enriched TSP) were tested at three sites, Vermont, Tourama and Belmont.

The soil and climate data for these areas are presented in Table 1. The experiment was laid down in a 4 x 4 latin square design at each site. The spacing used was 0.36 m^2. The rhizome pieces (setts) 50 +10 g were planted in land prepared by the existing method of cultivation (flat plowed). The fertilizer was applied in a split application of 500 kg. ha^{-1} at planting and again and at 6 weeks after emergence. Weeds were controlled manually.

Marketable yields were taken and exportable grade determined by technicians working with the Caribbean Agricultural Trading Company (CATCO) packing plant in St Vincent and the Grenadines. The cultivar was the St. Vincent large.

Experiment 2

Evaluation of different fertilizer rates required for both the existing system and the introduced technology from Dominica.

All treatment combinations of two levels of pen manure (0 and 10 t. ha^{-1}), two systems of land preparation,(furrow and flat) and four rates of Banana fertilizer, 400, 800, 1200 and 1600 kg.ha^{-1} were laid out in a split plot design. The main plots were cultivation systems by manure and fertilizer rates were the sub-plots. The fertilizer was banded around each plant. Main plots were replicated twice at each site, Akers and at Perseverance. The harvested area per sub-plot was 5 m^2. Flat cultivation was normal farmer's practice that is, hoe plowed, chip and plant. Furrow cultivation required trenches 15 cm wide and 30 to 40 cm in depth. The furrows were laid down 60 cm apart. The setts (50 +10 g) were planted 30 cm apart in the furrow. Pen manure was broadcasted at a rate of 10 t ha^{-1} in the furrow and tilled into the soil. The cultivar was the same as in experiment 1. Exportable grade was determined similarly as in experiment 1.

Experiment 3

The effect of reduced intra row spacing and system of cultivation on the exportable yield of ginger.

Six spacings of 15, 25, 35, 45, 55 and 65 cm within the row and an inter-row spacing of 60 cm were combined with two systems of land preparation, flat and furrow, as described previously. The experiment was laid down at two sites in a split-plot design with three blocks at each site. The main plot was land preparation systems with spacing being the sub-plot. The same St Vincent Large ginger cultivar was used. The exportable grade ginger was evaluated similarly as in experiment 1.

RESULTS AND DISCUSSION

Experiment 1

There was a significant interaction effect ($p<0.05$) of fertilizer formulation by sites (Fig. 1). The three areas produced the highest exportable yields from applications of 15-18-24 NPK and the yields were similar from the application of 15-08-24 NPK. Tourama district was noted for a lower annual rainfall (under 2000 mm) than the other two areas and produced a lower yield for all types of fertilizer (Table 1). Although sulphate of ammonia produced yields similar to 15-08-24 and 15-18-24 applications at Belmont, this fertilizer application resulted in significantly lower yields at both Toruma and Vermont. Except at Torouma, 18-18-05 applications resulted in lower yields. The nutrient potassium apparently affected production at Vermont and Belmont. The Vermont and Belmont soils belong to the group of old volcanic soils and fixed the phosphate before the plant could access the nutrient. This was due to the allophanic nature of the soil (Visser, 1991).

From the results, it can be cautiously recommended that farmers in Belmont or in similar eco-zones could use either sulphate of ammonia or 15-08-24. Farmers in the Tourama and Vermont area and other areas with soils of recent volcanic origin should use an NPK fertilizer such as the 15-08-24 or enriched phosphate 15-18-24 in preference to sulphate of ammonia. The most favorable area for growing ginger appeared to be Belmont, an area normally cultivated to this crop, followed by Vermont. In Tourama an area prone to rapid soil desiccation, mulching might be necessary. The potential for achieving more than 20 t. ha^{-1} of marketable ginger was demonstrated at all sites.

Experiment 2

Significant differences ($p<0.001$) were observed for the interaction of fertilizer rates and system of cultivation (Fig. 2) on exportable grade ginger. The increased rates showed improved yield of exportable grade ginger in flat cultivation, however the yield decreased for the higher application rates of fertilizer in furrow cultivation. The optimum rate in flat cultivation appears to be at 1.2 t. ha^{-1} and 0.4 t. ha^{-1} for furrow cultivation. Possibly the furrow (unplowed) treatment held the fertilizer for a longer period thus preventing any leaching that may have occurred in flat cultivation (plowed). Lee and Asher (1981), Lee et al (1981a) and Lee et al (1981b), reported that in Australia, little plant development took place in the first 50 days of growth. They also reported that farmers averaged yields around 26 to 37 t. ha^{-1} and these yields required only 40 kg to 110 kg. ha^{-1} of nitrogen. Therefore rates of 200 kg. ha^{-1} of N presently used was excessive in relation to plant needs. The observed higher soil moisture in the furrow probably assisted in fertilizer utilization by the plant. The response to increased rates of fertilizer on the flat gave the maximum exportable yield of 7 t. ha^{-1} compared to over 25 t. ha^{-1} for furrow cultivation at the lowest fertilizer rate. The combined yield of marketable and unmarketable rhizomes for both systems of cultivation were similar (Fig. 3) at the higher rates of fertilizer. However, at the lower rates of 0.4 t. ha^{-1} furrow cultivation produced significantly higher total rhizome yields.

The main reason for farmer rejection of the flat-cultivated ginger was the excessive branching of the rhizome, shortness of the rhizome piece and small size of hands. Breakage during harvest occurred more often with furrow cultivated than with flat cultivated ginger. However, in order to clean the flat cultivated ginger adequately, the rhizome had to be broken into small pieces. The furrow cultivated ginger required careful packing both in field and packing plant in boxes and not in bags. This type of ginger is not presently suitable for the regional trade where packaging for transport is in bags.

The interaction of system of cultivation by pen manure applications on exportable yields was highly ($p<0.01$) significant (Fig. 4). The increase in exportable yields in furrow cultivation was about 5 times as high as that obtained from flat cultivation (Fig. 4). Note that grading was done to meet the standards suggested by Medlicott (1990) and not necessarily the existing market demands. Pen manure gave a further 25% boost to total yields generally for both systems of cultivation (Fig. 5). Several workers have recommended the use of organic manure in ginger cultivation (Stephenson, 1989; Paliwal, 1988). The requirement of high humus levels in the soil is also documented by both Ridley (1912) and Purseglove (1981). The observed yield responses were therefore expected. However, it is important to note the contribution of pen manure to improved quality. Every effort should be made to use organic manure. The producer could be well rewarded depending on the cost of finding, transporting and applying the organic manure.

Experiment 3

Reduction in the intra-row spacing of ginger from 60 cm to 15 cm produced significantly ($p<0.01$) higher exportable yields of more than 20 t. ha^{-1} (Fig. 6). The existing spacing of 60 cm intra-row produced averaged yields of 10 t. ha^{-1} and was similar to reported yields on farmers holdings. Although reports show that spacing in India was 225 cm^2 (Ridley, 1912; Purseglove, 1981)) yet

the space remained at 3600 cm^2 per plant. Closer spacing improved yields on both flat and furrow cultivation.

The interaction of cultivation system and intra-row spacing showed no significant effect on either exportable grade ginger or total rhizome yields. Farmers can therefore reduce their intra-row nearer to 15 cm irrespective of the system of cultivation chosen. Flat cultivation had an overall significantly ($p<0.01$) lower exportable grade ginger at all spacings. The rhizome yields of furrow cultivation produced significantly higher yields (exportable and total) at all spacings compared to flat cultivation.

ECONOMIC ASSESSMENT

The combined results from the three experiments were made into an alternate technology compared to the existing cultivation system. The alternate technology consisted of a spacing at 25 cm intra-row by 60 cm inter-row, organic manure at 10 t. ha^{-1}, furrow cultivation, fertilizer NPK 15-08-18 at the rate of 500 kg. ha^{-1} in two split applications at 60 DAP and 120 DAP. This was compared to the existing technology to compute cost of production, each plot being approximately 2000 m^2. The alternate technology had a higher cost for crop establishment and maintenance (Table 2). This higher cost per hectare was offset by reduced cost per kg from EC \$1.31 kg^{-1} to EC \$0.57 kg^{-1} with the improved technology of spacing, furrow cultivation, fertilizers and manures. At a farm-gate price of EC \$0.88 kg^{-1} the net return for the improved technology is EC \$12,000.00 ha^{-1}. At a lower price of EC \$0.66 kg^{-1} the net return is EC \$3,600.00 ha^{-1}. The existing technology only showed profitability when no wages were paid for family labor.

CONCLUSIONS

The existing fertilizer formulation (15-08-24 NPK) is suitable at all locations and added phosphate showed only slight improvement in Vermont Valley.

Furrow cultivation not only required a lower rate of fertilizer but also improved yields and quality.

Organic manure is important and can increase exportable grade by 500% and overall yields by 25%.

Closer intra-row spacing produced higher yields and still gave enough room for crop management (e.g. moulding).

The combination of closer spacing, furrow cultivation with pen manure produces a profit in ginger production with the farmgate price at EC \$0.66 kg^{-1}. At this farmgate price, the existing traditional cultivation system results in a net loss to the producer.

The observation that furrow cultivated ginger is more easily broken because of the length of individual rhizomes should be noted. Harvest and post-harvest handling becomes more important with this method of cultivation. This method of cultivation depends on the market availability.

Table 1. Some characteristics of the soils where experiment 1 on ginger was carried out during 1990/91.

Characteristics	Tourama	Belmont valley	Vermont
pH	5.8	5.3	5.5
Nitrogen (NO_3)(ppm)	34	34	31
Phosphorus (P_2O_5)(ppm)	17.3	20.5	6.5
Potassium (K_2O)(ppm)	315	200	105
AEZ	IVa	111	111
Elevation (m)	60	120	60
Slope	15°	10°	10°
Rainfall(mm)	<2000	2000 to 2500	2000 to 2500
Soil Type	Recent volcanic ash	Yellow earth recent volcanic ash	High level yellow earth

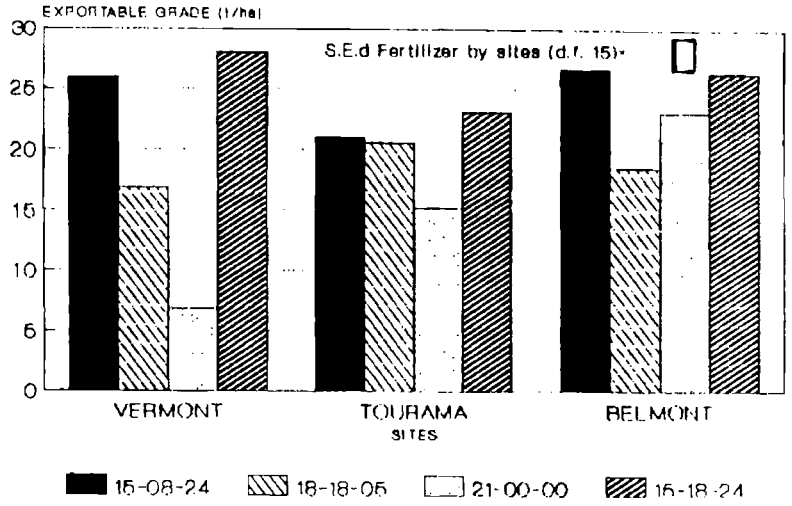
Source: CARDI, 1992. Annual Technical Report, St Vincent and the Grenadines.

Table 2. Economics of production for ginger grown under farmers condition and with improved cultivation techniques

Item/Technology	Farmer	Improved
Establishment ($/ha)*	7766	10332
Maintenance ($/ha)	4029	4729
Harvest ($/ha)	1699	3664
Post Harvest ($/ha)	1321	2850
Total Cost ($/ha)	**14814**	**21575**
Yields (kg/ha)	11322	38157
Cost/kg	**1.31**	**0.57**
Gross Income ($.88/kg)	9963	33578
Net Income ($.88/kg)	**(4851)**	**12003**
Gross Income ($.66/kg)	7473	25184
Net Income ($.66/kg)	**(7341)**	**3609**

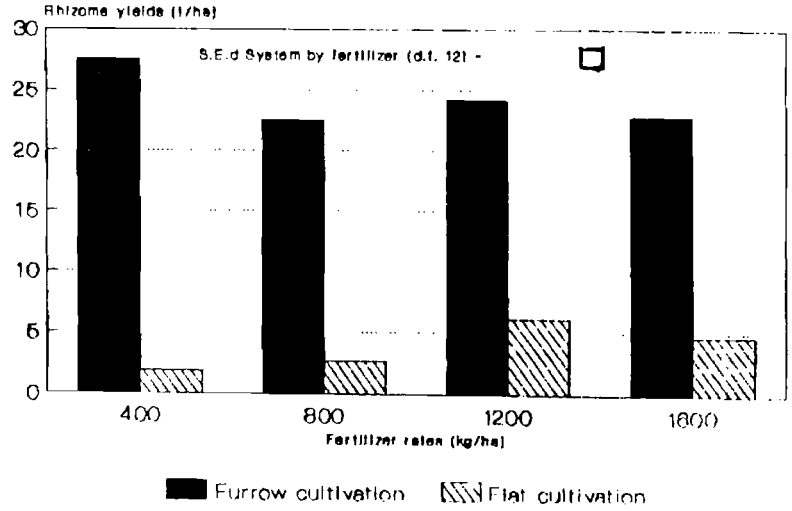
* US $1.00 = EC $2.70.

Figure 1. Effect of site by fertilizer formulation on the exportable grade yield of ginger



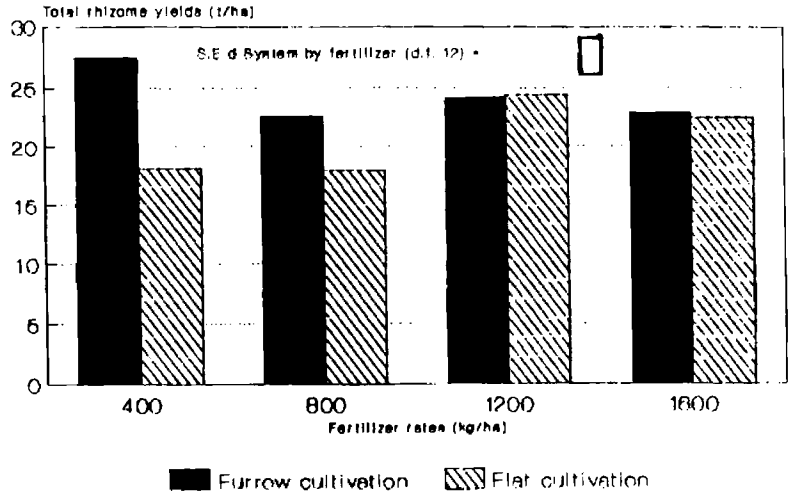
SITE: (3) IN ST VINCENT; 1990/91

Figure 2. Effect of cultivation system and fertilizer rates on the yield of exportable grade ginger



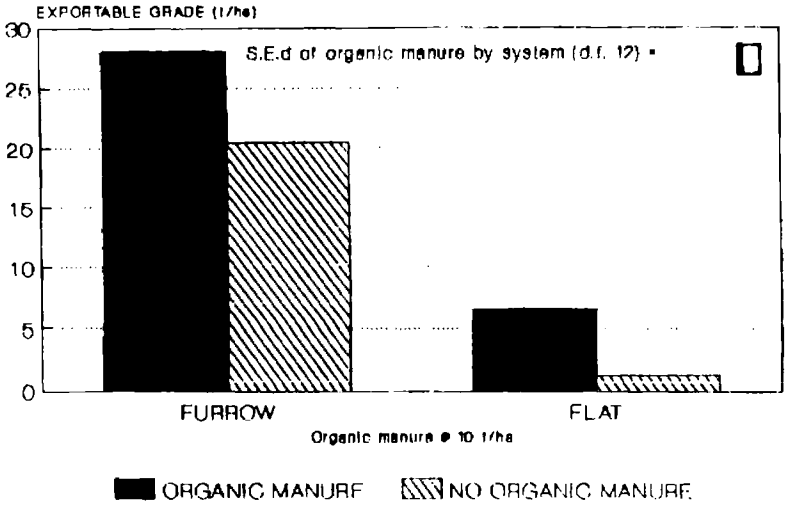
SITE: AKERS, ST VINCENT; 1990/91

Figure 3. Effect of cultivation system and fertilizer rates on the total yield of ginger fresh rhizomes



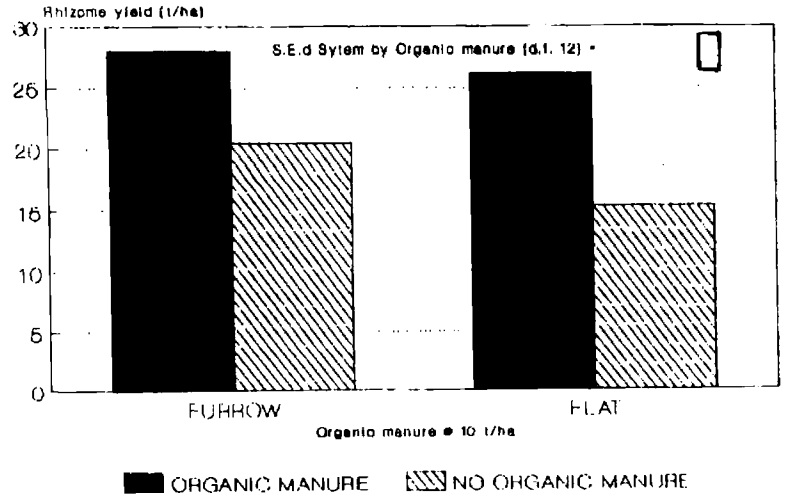
SITE: AKERS, ST VINCENT; 1990/91

Figure 4. Effect of organic manure and system of cultivation on the exportable grade yield of ginger



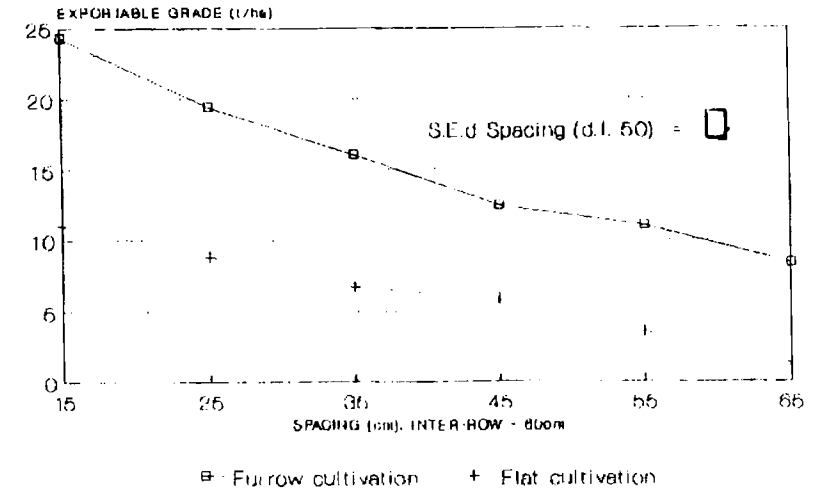
SITE.AKERS, ST VINCENT; 1990/91

Figure 5. Effect of organic manure and system of cultivation on the total fresh rhizome yield of ginger



SITE: AKERS, ST VINCENT; 1990/91

Figure 6. Effect of reduced intra-row spacing and cultivation systems on exportable grade yield of ginger



SITE: QUEENS DRIVE, ST VINCENT; 1990/91

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GROWTH AND YIELD RESPONSE OF THYME (*THYMUS VULGARIS* L.) TO SOURCES OF NITROGEN FERTILIZER

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ABSTRACT

The response of thyme (*Thymus vulgaris* L.) to sources of nitrogen (N) fertilizer application was studied in field experiments conducted in 1992 and 1993. Thyme plants were grown in plots consisting of 3 rows 2.1 m long with 40 cm between rows. In 1992, thyme plants were fertilized with N at a rate of 115 kg. ha^{-1} using N-source treatments of ammonium nitrate (35% N), ammonium sulfate (21% N), and urea (45% N). One treatment was applied with cow manure (2% N) at a rate of 230 kg N. ha^{-1}. A control plot (no N) was included as a treatment. In 1993, the same N fertilizer sources were used but N was applied at a rate of 100 kg. ha^{-1} for inorganic fertilizers and 200 kg. ha^{-1} for organic (cow manure) fertilizer. In both experiments phosphorus (P) and potassium (K) were applied at a rate similar to the P and K content of cow manure equivalent to 50 and 190 kg. ha in 1992 and 44 and 166 kg.ha^{-1} in 1993, respectively. In 1992, results indicated no significant differences in plant height, plant fresh yield and total dry matter yield among nitrogen fertilizer sources and the control. Results obtained in 1993 showed that urea and cow manure were superior to ammonium nitrate and the control in terms of total plant fresh yield. Plants fertilized with urea and cow manure produced total fresh yields of 7.5 and 7.2 t. ha^{-1}, respectively. Lowest plant fresh yield of 5.1 t. ha^{-1} was obtained from plots applied with ammonium nitrate. No significant differences in plant height were observed between treatments. It appears that urea and cow manure are the best sources of N fertilizer for thyme production in the Virgin Islands.

INTRODUCTION

Thyme (*Thymus vulgaris* L.) is one of the top selling culinary herbs in the Caribbean. It is commonly produced by small-scale vegetable and herb growers as well as home gardeners. Most of the thyme produced in the Virgin Islands are sold in local markets. However, there is potential for an export market since the U.S. mainland imports large quantities of herbs and spices annually from the Caribbean. Costa Rica, Dominican Republic, Jamaica, Puerto Rico and Trinidad are the major exporters of herbs and spices to the U.S. (USDA/ERS, 1993).

A major constraint to increased production of thyme in the Virgin Islands is the lack of technical information and recommended crop management practices. For example, there are no available information and guidelines on fertilizer application for herbs and spices. Most recommendations are based on other crops which have similar growth habit (Simon, 1987). Studies on fertilizer requirement of various herb species are important in determining what type of nutrient, formulation and rate of application will be optimum. The primary objective of this study was to determine the effect of sources of nitrogen fertilizer on the growth and yield of thyme.

REVIEW OF RELATED STUDIES

Herbs like other crops take nutrients from the soil during growth and development. As the availability of nutrients becomes depleted in the soil, the grower must add the nutrients back to the soil to ensure continued growth of the present and future plantings of the crop. Information on fertilizing herbs and medicinal plants is limited and often contradictory (Cox, 1992). This is

probably due to conflicting goals of producing herbs for maximum fresh and dry matter yields or growing herbs for maximum production of secondary products.

Nitrogen (N), phosphorus (P) and potassium (K) are the major nutrients required by herbs and thus fertilizers containing these elements are the most widely used. Of these fertilizer elements, the largest growth and yield response in herbs generally results from nitrogen application (Cox, 1992). The first increments of N added to the soil are almost always effective in increasing dry matter yields and secondary product accumulation in herbs. Further increases in N application generally do not result in large yield increase. High N fertilization may actually reduce plant growth and accumulation of secondary products. Such a relationship between N levels and plant response has been observed in such diverse species as poppy (Laughlin, 1983), peppermint (Hornok, 1983), lovage (Galambosi and Galambosi, 1992) and rosemary (Boyle and Craker, 1991).

The source and form of N fertilizer can also affect growth and yield as well as the quality of secondary products in herbs. Although N is absorbed by plant roots in either ammonium (NH_4^+) or nitrate (NO_3^-), some plants species seem to prefer one N form over the other while other plants have no preference. For example, sweet basil plants fertilized with NH_4-N contains less linalool and eugenol oils than plants fertilized with NO_3-N (Adler, et al., 1989). Ammonium form of N had similar effects on the production of essential oil in Japanese mint (Singh and Singh, 1978). In one study, NH_4-N limited the production of alkaloids in poppy (Costes, et al., 1978), but these results could not be duplicated in a second study (Laughlin, 1983).

There are few studies comparing the effects of sources of N fertilizer on fresh and dry matter yields of herbs and spices. In a related study using various levels of ammonium nitrate in combination with P and K and micronutrients, it was found that sweet basil, sweet marjoram, pot marjoram and oregano responded favorably to 168 and 252 kg N. ha^{-1} (Angell, et al., 1990). Experiments in Virgin Islands showed that using urea, the cumulative fresh and dry matter yields of thyme with N applications of 112 and 169 kg. ha^{-1} were superior to the control (no nitrogen) treatment (Crossman and Collingwood, 1991).

MATERIALS AND METHODS

The experiments were conducted at the Agricultural Experiment Station, University of the Virgin Islands on St. Croix (Lat. 17°42'N and Long. 64°48'W). The soil is Fredensborg loamy, fine carbonatic, isohyperthermic, shallow, typic calciustolls. The initial soil analysis showed a soil pH of 7.98, organic matter content of 4.15%, 19 ppm P, 345 ppm K, and a CEC of 25 meq/100 g. The average annual rainfall is 1016 mm, but evapotranspiration exceeds precipitation 10 months of the year resulting in a negative water balance.

The experiments were established using a randomized complete block design with four replications. The treatments consisted of N sources coming from ammonium nitrate (35% N), ammonium sulfate (21% N), urea (45% N) and dry cow manure (2% N). A control plot (no fertilizer N) was added as a treatment. In 1992, thyme plants were fertilized with N at a rate of 115 kg. ha^{-1} using the various N fertilizer sources, except the cow manure where N was applied at a rate of 230 kg. ha^{-1}. In 1993, similar N fertilizer sources were used, but N was applied at a rate of 100 kg. ha^{-1} for inorganic fertilizers and 200 kg. ha^{-1} for organic (cow manure) fertilizer. In both experiments, P and K were applied at rates similar to P and K contents of cow manure (50 and 190 kg. ha^{-1} in 1992 and 44 and 166 kg.ha^{-1} in 1993, respectively). The inorganic fertilizers were applied in bands at the base of each plant. Nitrogen was applied in 2 and 3 splits in 1992 and 1993, respectively. All the P and K were applied at planting. All of the cow manure was applied at planting. Thyme seedlings were planted in plots measuring 3 m long by 1.2 m wide. Each plot consisted of 3 rows spaced at 30 cm. Plants were spaced 30 cm within rows. All plots were drip irrigated to maintain soil moisture tension at 30 kPa.

In 1992, the plants were harvested on March 11 and June 15. Yield samples were taken from middle rows. Plants were cut at the base and weighed. Stems were separated from leaves and each

component weighed and oven-dried at 70°C. In the 1992-93 trial, plants were harvested on December 21, 1992 and March 24, 1993. Similar sampling procedures and data collection were followed as in 1992. Plant height was measured at every harvest using 10 plants in middle rows. To determine the effect of N fertilizer source on nutrient content of thyme, leaf samples were analyzed for the major and minor elements. Likewise, initial and final soil pH were measured to determine the influence of N fertilizer source on soil pH. All data were statistically analyzed using the Statistiscal Analysis System (SAS) GLM procedure. Significant differences among treatment means were determined using the Duncan's Multiple Range Test.

RESULTS AND DISCUSSION

Plant Height, Fresh and Dry Matter Yield, 1992 Trial

Nitrogen fertilizer source did not influence plant height or fresh and dry matter yields of thyme in the 1992 trial (Table 1). In fact, plants in the control plots (no N fertilizer) were slightly taller and had slightly higher yield than plants in the fertilized plots. The high initial soil organic matter content may explain this small difference. Generally, yields from the first harvest were higher than the second harvest in all treatments. After the first harvest some plants were infected by a soil borne fungus which resulted in gradual die back. Fungal infection was random and occurred in all treatments. Although dead plants were replanted, growth of new transplants was slow to catch up with mature plants. The relatively low yield of the second harvest may be attributed to this fungal infection.

Plant Height, Fresh and Dry Matter Yield, 1993 Trial

There were significant differences among treatments in fresh and dry matter yields, but not in plant height in the 1993 trial (Table 2). Total fresh thyme and dry matter yield were highest (7.45 and 2.16 t. ha^{-1}) in plots fertilized with urea and lowest (5.07 and 1.31 t. ha^{-1}) in ammonim nitrate plot. Differences in fresh thyme yield were not significant between urea, cow manure and ammonium sulfate, but urea and cow manure were superior to ammonium nitrate and the control. This trend was similar for dry matter yield. There was no significant difference in plant yield between ammonium nitrate and ammonium sulfate- fertilized plots, although plants applied with ammonium sulfate resulted in slightly higher yield than plants fertilized with ammonium nitrate. Yield from plots applied with ammonium nitrate resulted in similar yield to the control plots (Table 2). Similar soil borne fungal disease was observed in 1993. The incidence was common after the first harvest which resulted in lower yield of the second harvest.

The yield data indicate that urea and cow manure are better sources of N fertilizer for thyme compared to ammonium nitrate and ammonium sulfate. This would also suggest that organic fertilizers might be beneficial for thyme production.

Leaf Nutrient Content

In 1993, leaf samples from plants fertilized with various N fertilizer sources were analyzed for contents of major and minor elements. Results indicate that for the major nutrients, there were no significant differences among treatments, except for magnesium content (Table 3). Leaf samples from plants fertilized with ammonium nitrate and ammonium sulfate were higher in magnesium content than other treatments. Except for boron, the minor nutrient content of thyme leaves were not significantly affected by sources of N fertilizer (Table 4). This indicates that sources of N fertilizer have little influence on the nutrient content of thyme.

Changes in Soil pH

All treatments resulted in slight increase of soil pH after harvest as shown in Table 5. The highest increase was from plots fertilized with ammonium nitrate followed by plots applied with urea (Table 5). These treatments resulted in soil pH increments of 0.40 and 0.27, respectively. The lowest increment was observed in the control plots (0.11). Plots applied with ammonium sulfate resulted in soil pH change from 8.12 to 8.28, a 0.16 increment. It has been reported that continuous application of fertilizers containing sulfur such as ammonium sulfate will result in decrease of soil pH (Lathwell and Reid, 1984; Lorenz and Maynard, 1988), but in this short term study, this change was not observed. In calcareous soils, such as in the Virgin Islands, continuous use of fertilizers containing ammonium may be detrimental to plant growth as these fertilizers raise the soil pH which is already alkaline. Since the increase in soil pH was slight in all fertilizer treatments, it may take several years of fertilizer application before the effect on plant growth can be observed

CONCLUSIONS

The response of thyme to sources of N fertilizer was studied in two trials conducted in 1992 and 1993. The results showed no response in 1992 in terms of plant height, fresh and dry matter yields. In 1993, significant differences were seen among treatments. Urea and cow manure were superior to ammonium nitrate and the control in both the fresh and dry matter yields. Except for magnesium and boron, all treatments did not significantly change the nutrient contents of thyme leaves. All treatments resulted in slight increase in soil pH, but the least pH change was in the control and plots applied with ammonium sulfate. Based on this study, it appears that urea and cow manure are best sources of N fertilizer for thyme production in the Virgin Islands.

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Table 1. Plant height, total fresh and dry matter yields (t ha^{-1}) of thyme applied with various sources of nitrogen fertilizer, 1992.

Nitrogen Source	Plant height (cm)[1]	Plant Fresh Yld (1)[2]	Plant Fresh Yld (2)[3]	Total Fresh Yld	Dry Matter Yld (1)[2]	Dry Matter Yld (2)[3]	Total Dry Matter
NH_4NO_3	23.0	10.0	9.47	19.5	3.48	3.43	6.91
$(NH_4)_2SO_4$	21.8	11.6	6.91	18.5	3.77	2.52	6.29
Urea	21.6	9.8	8.05	17.9	3.33	2.93	6.26
C. Manure	23.0	11.8	5.83	17.6	3.95	2.17	6.12
Control	23.7	10.6	9.68	20.3	3.72	3.48	7.20
Pr>F	NS	NS	NS	NS	NS	NS	NS

[1]Measured at first harvest. NS=not significant
[2]Yield of 1st harvest
[3]Yield of 2nd harvest

Table 2 . Plant height, total fresh and dry matter yields (t ha^{-1}) of thyme applied with various sources of nitrogen fertilizer, 1993.

Nitrogen Source	Plant height (cm)[1]	Plant Fresh Yld (1)	Plant Fresh Yld (2)	Total Fresh Yld	Dry Matter Yld (1)	Dry Matter Yld (2)	Total Dry Matter
NH_4NO_3	19.8 a	3.03 bc	2.04 b	5.07 b	0.81 ab	0.50 b	1.31 c
$(NH_4)_2SO_4$	19.9 a	2.56 c	3.42 a	5.98 ab	0.68 b	0.94 a	1.62 abc
Urea	18.7 a	4.12 ab	3.33 a	7.45 a	1.25 ab	0.91 a	2.16 a
C. Manure	19.9 a	5.23 a	1.93 b	7.16 a	1.35 a	0.60 ab	1.95 ab
Control	18.3 a	3.33 bc	2.15 b	5.48 b	0.85 ab	0.58 ab	1.43 c

[1]Measured at first harvest
[2]Yield of 1st harvest
[3]Yield of 2nd harvest
For each column, values with common letters are not significantly different (P=0.05)

Table 3. Major nutrient content (%) of thyme leaves as affected by sources of nitrogen fertilizer, 1993.

Nitrogen Source	N	P	K	Ca	Mg
NH_4NO_3	3.08	0.30	3.65	1.52	0.30
$(NH_4)_2SO_4$	3.01	0.27	3.02	1.31	0.32
Urea	2.82	0.29	3.41	1.35	0.28
Cow Manure	2.80	0.26	2.87	1.46	0.28
Control	2.82	0.27	3.20	1.31	0.27
Prob>F	NS	NS	NS	NS	*

*Significant at P=0.05. NS = not significant

Table 4. Minor nutrient content (ppm) of thyme leaves as affected by sources of nitrogen fertilizer, 1993.

Nitrogen Source	Al	Bo	Cu	Fe	Mn	Zn
NH_4NO_3	1380	24.6	12.8	846	210	36.1
$(NH_4)_2SO_4$	1197	25.2	13.2	738	214	35.3
Urea	1291	23.8	14.0	798	203	37.7
Cow Manure	1557	30.3	11.8	952	191	39.4
Control	1283	25.9	13.0	787	197	38.8
Prob>F	NS	**	NS	NS	NS	NS

**Significant at P=0.01. NS = not significant

Table 5. Changes in soil pH as influenced by sources of nitrogen fertilizer.

Nitrogen Source	Initial pH	Final pH	Difference
NH_4NO_3	8.12	8.52	0.40
$(NH_4)_2SO_4$	8.12	8.28	0.16
Urea	8.12	8.39	0.27
Cow Manure	8.12	8.31	0.19
Control	8.12	8.23	0.11

THE EFFECT OF VARYING RATES OF NITROGEN AND IRRIGATION ON YAM (*DIOSCOREA ALATA* L.) PRODUCTION

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ABSTRACT

A series of studies were conducted to evaluate the effects of varying rates of nitrogen fertilizer and applied irrigation, on yam production. Yam was grown in field trials with nitrogen applied at rates of 0, 100, 200 and 300 kg/ha. The application of nitrogen did not affect the production of yam tubers from either of two cultivars ('Binugas' and 'Gunung'). Yields were similar for both cultivars at all nitrogen levels. The results of another study showed that nitrogen applied to 'Gunung' at rates of 0, 50, 100 and 150 kg/ha significantly affected yield and dry matter production. Yam production decreased linearly as nitrogen rates increased. Two trials were conducted to evaluate the effect of varying irrigation rates (rain-fed and soil moisture maintained at 20, 40 and 60 kPa) on the production of 'Binugas' yams. The application of irrigation quadratically decreased the dry matter content of the yam tubers, in both trials.

INTRODUCTION

Yam, plants of the genus *Dioscorea*, is an important crop in the Caribbean, where production ranks second only to West Africa (Onwueme,1978). Due to high production costs, prices are higher for yam than for other tropical root crops.

Compared to other root crops, yam requires the most intensive management in order to obtain a high yield of good quality tubers. This includes proper plant nutrition and maintaining the soil moisture at optimum levels.

Even though yams are a popular food crop in the Virgin Islands, where prices for this crop are higher than for other tropical root crops, production in 1987 had declined drastically to approximately 20 percent of 1960 production levels. This was due primarily to a concurrent reduction in harvested agricultural cropland, which in 1987, was approximately 15 percent of the 1960 acreage (Moore, 1991). If this trend of reduced harvested cropland acreage continues, then production per unit land area must be increased to at least maintain the present level of local yam production. Yields can be substantially increased if factors including plant nutrition and water requirement are given adequate attention.

Even though many trials have been conducted in Africa and the Caribbean to determine the response of yams to fertilizer, minimal research of this nature has been conducted in the Virgin islands. Intensively managed and fertilized yams in Puerto Rico produced very high yields of marketable tubers and edible dry matter (Irrizary and Rivera,1985). Results of these trials have been inconsistent but positive responses have been reported in Africa and the Caribbean by Rouanet, 1976; Ferguson and Haynes ,1970; Gooding, 1970, 1971; Gurnah, 1974; and Igwilo, 1989. The level of these responses was affected by the accompanying cultural practices.

Different yam cultivars have been found to respond differently to the same fertilizer application (Ferguson and Haynes, 1970; Obigbesan et al., 1977). It is therefore important to know the response potential of the various yam cultivars to fertilizer applications. Responses will vary based upon soil type and local climatic conditions (Ferguson, 1980).

Koli (1973) reported that nitrogen was the most important nutrient element because its application significantly increases yields. Ferguson and Haynes (1970) found that compared with other crops, such as cereals, yam is relatively insensitive to nitrogen shortage. Lyonga (1982) found that applications of N at 60 days after planting gave better yields than earlier or later applications. The element appears desirable during the first half of the growing season. Subolo (1972) and Obigbesan and Agboola (1978) reported that yams extracted large quantities of N from the soil. Applications of N are most beneficial if available when the plants changes dependence from the seed piece to autotrophy. At this time the root system is extensive enough to absorb and utilize the fertilizer. Plants can then develop a large leaf area which provides a sufficiently large photosynthetic area for rapid tuber development and growth.

Yams do not tolerate prolonged periods of drought without a drastic yield reduction especially during the critical 2-3 month period when all of the food reserves of the seed piece has been exhausted. Moisture stress also delays tuber initiation. Tubers develop best when rainfall is frequent, so that the soil is almost constantly wet, but they also require good drainage for best growth. Gooding (1970, 1971) reported yield increases with increased rainfall up to 100 cm during the growing season.

Yams are traditionally grown by small farmers under rain-fed, subsistence conditions characterized by lack of fertilizer and pesticides. This management practice involves small investments, low risks, but results in low productivity and low income. Environmental conditions in the Virgin Islands pose stress conditions for plant growth - low annual rainfall, heavy soils, high soil pH and associated deficiencies in P and micronutrients.

The objectives of these studies were to evaluate the effect of nitrogen and irrigation application on the yield, tuber size and dry matter production of *D. alata* cultivars.

MATERIALS AND METHODS

The studies were conducted at the University of the Virgin Islands - Agricultural Experiment Station on St. Croix. The soil is a Fredensborg loamy, fine, carbonatic, isohyperthermic, shallow, typic calciustoll (Lugo-lopez and Rivera, 1980).

Two trials were conducted to evaluate the effect of varying rates of nitrogen on the production of *D. alata* cultivars. In the first trial ammonium sulfate was split-applied to provide nitrogen at rates of 0,100, 200 and 300 kg/ha to plots planted with cultivars 'Binugas' and 'Gunung'. The first half of the nitrogen and all of the phosphorous (100 kg/ha using triple super phosphate) was applied at one month after planting. The second half of the nitrogen and all of the potassium (100 kg/ha using potassium sulfate) was applied at 3 months after planting. The soil pH was 7.8 for both trials and soil N was 116 and 95 ppm for 'Binugas' and 'Gunung', respectively (Table 1).

Field plots were established using sprouted yam tuber pieces weighing approx. 115 g. as the planting material. Plots were 3 m x 3.7 m and consisted of 3 rows (ridges), spaced 1 m apart. Plants were spaced 0.3 m within rows. The experimental design was a randomized complete block with four replications. A drip irrigation system was installed consisting of 1.27 cm poly-hose (Hardie Irrigation) as the sub-mains and Drip Strip Plus (Hardie Irrigation) tubing with laser drilled orifices 0.3 m apart as the laterals.

Each plot was harvested at 6 months after planting. Tubers from 10 plants in the center row of each plot were harvested. The weight of marketable tubers was recorded.

In a second trial cultivar 'Gunung' was evaluated for the effect of nitrogen applied at varying rates. Ammonium sulfate was applied to provide nitrogen at rates of 0, 50, 100 and 150 kg/ha. Phosphorous and potassium were both applied at rates of 75 kg/ha using triple super phosphate and potassium sulfate, respectively. All of the fertilizer was applied two months after planting. The initial soil pH was 7.9 with a N content of 90 ppm (Table 1). The experimental design, plot size, layout and establishment, and harvesting method were similar to the previous trial. At harvest (seven months after planting), the total and marketable weight of tubers were recorded. Tuber sub-

samples from each replication were peeled, sliced, then dried at 70°C to obtain the dry matter content.

Two trials were conducted to evaluate the effect of varying irrigation rates on the production of *D.alata* yams. Cultivar 'Binugas' was grown in field plots with irrigation applied to maintain soil moisture levels of 20, 40 and 60 kPa. A rain-fed (no applied irrigation) treatment was also included. Nitrogen was applied at 100 kg/ha using ammonium sulfate, and P and K were both applied at 75 kg/ha (using triple super phosphate and potassium sulfate, respectively). Asimilar drip irrigation system as previously described was installed in trial plots. Tensiometers (Irrometer Co., CA) were placed in the root- zone in the center rows of plots, to monitor soil moisture content. When tensiometer readings exceeded the level for a specific treatment, the irrigation system was turned on until the soil moisture content was increased to the desired level. Semi-automatic timers were used to turn the irrigation system on and off . Water flow meters were used to measure the amounts of water applied to each treatment. The experimental design, plot sizes, layout, establishment, harvesting method and dry matter content determination were similar to the nitrogen rate trials. Rainfall during the 1992 and 1993 growing seasons were 830 and 511 mm, respectively (Fig .1). Yams were harvested at seven and six months after planting in 1992 and 1993, respectively.

Statistical analyses of data were performed following the statistical analysis system procedures (SAS Institute, Inc. 1988).

RESULTS AND DISCUSSION

The application of nitrogen at rates up to 300 kg/ha did not affect production of either of the two cultivars ('Binugas and 'Gunung') utilized in the study. Yields were very similar for both cultivars at all application rates, and there was a trend for higher yields from the 0 nitrogen plots.

Production of 'Gunung' yams was influenced by the nitrogen fertilization treatments in the second trial. There was a negative linear response of total and marketable yields to the rates of applied nitrogen (Table 2). Yields decreased as the nitrogen application rate increased. The percent dry matter of the tubers was not affected by the treatments but total dry matter production had a linear response (Table 2). Nitrogen applied at the low rates (0-50 kg/ha) produced higher yields and dry matter than at the higher rates (100-150 kg/ha).

These trials have indicated that supplemental applications of nitrogen to soils testing at nitrogen levels of 95 to 116 ppm will suppress yam yields in the Virgin Islands. A lack of response to high levels of N have been reported in Barbados by Gooding (1970), and yields were decreased in Trinidad (Chapman, 1965).

The response pattern to the irrigation rates was similar for both years. Yields were much higher in the first year probably due to the longer growing season. During both growing seasons the only parameter to be influenced by the application of irrigation was the dry matter content of the tubers Tables 3 and 4). There was a quadratic decrease in dry matter content as the irrigation rate, hence the soil moisture content, increased.

The water use efficiency data for both years (Tables 5 and 6) indicate that rainfall was the biggest contributor to soil moisture during the growing season (336.6 and 206.7 m^3 for 1992 and 1993, respectively). The yield data indicates that despite a higher rainfall amount during the 1992 growing season, a more beneficial response to supplemental irrigation was obtained during the longer growing season compared to 1993. Irrigation was an economically viable practice, but was more beneficial during 1992. Irrigation returns were similar for the 60 kPa treatment for both years but were much higher for the 20 and 40 kPa treatments in 1992 ($102 for both treatments) than 1993 ($40 and $67 for the 20 and 40 kPa treatments, respectively) .

Rainfall amounts of 511 to 830 mm during a six to seven months growing season appears to be adequate for yam production. A longer growing period definitely results in increased yield and increased water use efficiency.

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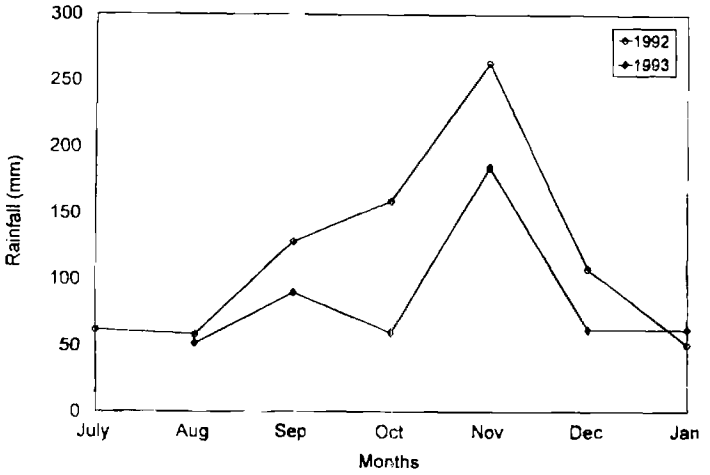

Figure 1. Monthly rainfall amounts during 1992 and 1993 yam growing seasons.

Table 1. Soil test data for plots used in yam nitrogen application trials.

Cultivar (YR)	N (ppm)	P (ppm)	K (ppm)	Ca (ppm)	pH	OM (%)
BINUGAS (1992)	116	14	343	4250	7.8	6
GUNUNG (1992)	95	3	328	4017	7.8	2.5
GUNUNG (1993)	90	18.4	343	4556	7.9	4.4

Table 2. Effect of applied nitrogen on 'Gunung' yam production.

Nitrogen rate (kg/ha)	Size (g)	Total yield (t/ha)	Marketable yield (t/ha)	Dry matter (%)	Total dry matter (t/ha)
0	480	23.9	18.5	20.5	4.9
50	372	21.4	18.1	19.6	4.2
100	465	18.1	15.1	19.7	3.6
150	253	10.5	7.6	19.3	2.1
Significance	NS	L**	L*	NS	L**
Contrasts					
Low vs High	NS	*	*	NS	**
0 vs 150	NS	**	*	NS	**
50 vs 150	NS	*	*	NS	*

NS, *, ** Nonsignificant or significant at P = 0.05 or 0.01, respectively.
Linear (L) response.

Table 3. Effect of irrigation on 'Binugas' yam production (1992).

Irrigation rate (kPa)	Tuber Size (g)	Total yield (t/ha)	Marketable yield (t/ha)	Dry matter (%)	Total dry matter (t/ha)
20	500	25.2	23.5	21	5.3
40	480	23.8	20.7	20.9	5
60	775	23 8	21.6	21.8	5.2
Rain	357	20 2	17.1	22.6	4.6
Significance	NS	NS	NS	Q*	NS

NS,* Nonsignificant or significant at P = 0.05
Quadratic (Q) response.

Table 4. Effect of irrigation on 'Binugas' yam production (1993).

Irrigation rate (kPa)	Tuber Size (g)	Total yield (t/ha)	Marketable yield (t/ha)	Dry matter (%)	Total dry matter (t/ha)
20	308	14	10.1	18.3	2.5
40	367	16.2	9.8	17.4	2.8
60	336	13.2	8.7	18.9	2.5
Rain	373	14.8	10.4	19.7	3.1
Significance	NS	NS	NS	Q**	NS

NS,** Nonsignificant or significant at P = 0.01
Quadratic (Q) response.

Table 5. Estimated water use (applied) and efficiency of irrigated 'Binugas' yam (1992).

Irrigation rate (kPa)	Total Water use (l/plt)	Total Water use (cu. m)	Irrigation water cost ($/ha)	Water cost efficiency ($/t)	Returns to irrigation water ($/$)
20	4.6	153.0	647.2	27.5	101.8
40	4.1	135.0	571.1	27.6	101.6
60	3.2	105.6	447.3	20.8	135
Rain[1]	10.1	336.6	-	-	-

Water cost = $4.23/cu m
[1]Rainfall computed based on 1 mm =4047 l
Yam price = $2.80/kg
Water cost efficiency = cost of water to produce 1 ton of yam

Table 6. Estimated water use (applied) and efficiency of irrigated 'Binugas' yam (1993).

Irrigation rate (kPa)	Total Water use (l/plt)	(cu. m)	Irrigation water cost ($/ha)	Water cost efficiency ($/t)	Returns to irrigation water ($/$)
20	5.1	168.8	713.8	70.8	39.5
40	2.9	96.8	409.3	41.8	67.1
60	1.4	45.0	190.4	21.9	127.7
Rain[1]	6.2	206.7	-	-	-

Water cost = $4.23/cu m
[1]Rainfall computed based on 1 mm = 4047 l
Yam price=$2.60/kg
Water cost efficiency = cost of water to produce 1 ton of yam

EFFECTS OF SETT SIZE, SETT TYPE, MULCHING AND STAKING ON TUBER YIELD PRODUCED FROM YELLOW YAM (*DIOSCOREA CAYENENSIS* L.) MINISETTS

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ABSTRACT

The value of Jamaican yellow yam (*Dioscorea cayenensis*) exported in 1992 was US$9.9m. These yams are produced in a traditional system where all yams are staked and planted on individual mounds. The traditional system of production contributes to soil erosion on the hillsides where most of the crop is grown. Based on the importance of the crop, the minisett system of production was introduced to improve the system of production. Four on-farm trials were conducted to determine the effects of sett type. sett sizes, staking and mulch on tuber yield from yellow yam minisetts. It was found that sett size and type did not affect total tuber yield. A quantitative assessment of the number and weight of marketable tubers produced in defined weight categories showed that tuber size was influenced by staking and mulching. Experimental yields from 17.7 t/ha to30.9t/ha were higher than national average yield of 12t/ha.Agronomic implications were discussed.

INTRODUCTION

In 1992 the value of yams (*Dioscorea spp.*) exported from Jamaica was US$9.9m (Planning Institute of Jamaica, 1993). Yams are grown for local consumption but a growing export market has facilitated the expansion of production and farmers are interested in producing tubers for export. However, the production of yam forms part of a very diversified system on small farms where proper proportioning of farm labor to meet the demand of all the enterprises has resulted in management inefficiencies (Payne, 1976). Rankine (1974) found that labor represented 30-60% of the total cost of producing the crop and that the farm family provided 52% of the labor required. All yams are planted on individual mounds spaced 2m x 2m to 3m x 3m apart with two to three setts weighing between 0.5kg and 4kg on each mound (Ferguson, Rankine and Bennett 1985). The portion of the tuber which is proximal to the vine and referred to as the"head" is the normal planting material. The vines are supported with poles 3m to 7m long. Between 4.5t/ha and 10.2t/ha of heads are planted to produce average yields of 12t/ha (Payne 1976).

The minisett system of production was introduced to Jamaica in 1985 to improve the system of production. The system which was developed in Nigeria, involves the cutting of whole tubers into setts weighing approximately 25g and planted at high densities, however, due to the low percentage sprouting of 25g minisetts of yellow yam a modified technological package using 120g setts was introduced to farmers with the objective to produce marketable tubers in one growing season. The modified minisett production system involves the use of pre-sprouted setts, planting on continuous mounds and mulching with plastic. Kalu, Norman, Paland Adedzwa (1988), found that under African savanna conditions,more marketable tubers were produced from *D. alata* and *D.esculenta* than *D. rotundata* and *D. cayenensis* when minisetts of the same size were used. Onwueme (1981) described a non-staking system of producing yams which was less laborious and yielded as much as the traditional system. It has been suggested that yam production should move towards mechanized operations and reduced requirements for stakes (Wilson 1982).This paper evaluated the effects of sett characteristics (type and size) and agronomic practices (mulching and staking) on the production of marketable tubers within the modified minisett technological package for producing yellow yams in Jamaica.

MATERIALS AND METHODS

Four on-farm trials were conducted in the Guys Hill area of St. Catherine at an elevation of 1000m and on soil type classified as Wirefence Clay Loam in the Jamaican soil classification. Dormant tubers were cut into setts weighing 120g and dipped in a mixture of 20g fungaflor and 150ml oxamyl solution in 80l of water. The setts were air dried for 1 day and then presproutedin moist saw dust. To reduce variability due to differences in physiological maturity in the planting material, only setts that sprouted at the same time were selected for the experiments which allowed each experiment to be planted out in one day. Setts were prepared from the proximal (head), middle and distal(tail) portions of the tuber. In all the experiments except formulched double row plantings, the sprouted setts were transplanted 30cm apart along the row on ridges spaced 90cm apart. The ridges were covered with plastic mulch after a rainfall event.

The first experiment compared two sett sizes, 120g and 200g. Each plot was 3.5m x 3.6m. The experiment was planted on May 15, 1991 and harvested on February 24, 1992. A randomized block design with four replicates was used. In the second experiment head, middle and tail setts which sprouted at the same time were transplanted into separate plots based on sett type. Each plot was 3.3m x 3.6m with four rows of 11 plants each. Theexperiment was planted in December 1990 and harvested in August 1991. A randomized complete block design with three treatments and three replicates was used. The third experiment, examined the effect of staking on yield. One month after planting the minisett vines in the staked treatment were supported with poles 1.2m long. A randomized block design with staked and unstaked treatments and three replicates was used. Each plot was 4.5m x3.6m and comprised of four rows of 15 plants. The plot was hand-weeded twice during the life of the crop. The experiment was planted in January, 1991 and harvested in October, 1991. In the fourth experiment, a split-plot design with three replicates, and having single and double row production systems as the main plots, and mulch and no mulch subplot treatments was used. For single row plantings, the setts were spaced 30cm in a single row on ridges spaced 90cm apart. In the double row planting, two rows of setts were planted 30cm along the row on each ridge; the ridges were spaced 1.5m apart. Each plot was 9mx 5m. The experiment was planted on December 14, 1990 and harvested on October 3, 1991.

In light of the fact that marketable tuber size can change, aquantitative assessment was made of tubers in different size categories. Marketable tuber yield was analyzed for two market categories. Market 1 consisted of tubers with a minimum size of 0.3kg and market 2 consisted of tubers weighing more than 1.3kg. The data were analyzed using analysis of variance and chisquare.

RESULTS

There was wide variation in the tuber size produced from minisetts in all the experiments. Variation in tuber size within plots was sometimes greater than the variation between plots. Tuber size ranged from 0.1-3kg with a large proportion of the tubers in the size range 0.3-1.3kg (Figs.1-4). There was no significant difference ($p>0.05$) in total tuber yield due to sett size (Table I), sett type (Table II) and mulching (Table IV). Total tuber yield was 52% higher ($p<0.5$) for minisetts with vines that were staked than for those which were not staked (Table III). For both markets, market 1($p<0.01$) and market 2 ($p<0.001$) proportionately more marketable tubers were obtained from the plots that were staked(Table VII). Although a larger number of marketable tubers was produced from 200g setts than from 120g setts the difference was not significant (Table V) ($p>0.05$). The number of marketable tubers was not influenced by sett type (Table VI). There was interaction between row and mulched plots with the highest number of large tubers produced from single row mulched treatments for both market 1 ($p<0.01$) and market 2 ($p<0.1$)(Table VIII).

DISCUSSION

It was demonstrated that staking increased the total tuber yield of yellow yam minisetts which is in keeping with earlier reports. In Jamaica yields from plots where large yam heads were planted and staked with long poles were generally superior to plots where shorter poles were used (Payne, 1973). Increased yield from staked minisetts in this study was attributed to the production of a larger number of tubers weighing more than 1.3kg which is advantageous to the farmer since the market for tubersless than 1.3kg has not been developed.

This study was comprised of simple experiments and placed great emphasis on reducing variability in the planting material as a means of providing reliable results. Given that the experiment shad few degrees of freedom, any detectable difference was likely to have significant implications for farmers. Based on these it is recommended that minisetts be staked for the production of larger tubers. Staking may have increased the photosyntheticability of the plant through increasing leaf exposure or reduced the competition between vines of neighboring plants.

It was found that the size and type of sett did not affect total yield, thus all portions of the tuber can be used for planting. In previous reports, the effect of sett type was not always marked and since these experiments were planted with setts that sprouted at the same time, the difference in results may be due to the use of setts that sprouted at the same time while earlier studies tended to compare yield from setts of different physiological age and which were planted out over a period of time depending on the time of sprouting.

In studies on-farm with yams, Gooding (1971), found that simple experiments were capable of yielding a considerable amount of information from which trends can be deduced. Examination ofthe tuber population at harvest emphasized the presence of relatively large proportions of small tubers. It was observed that the variability in tuber size was sometimes greater than the variability between plots. A more detailed study of tubersize distribution revealed that there were differences in the number of marketable tubers due to the effects of staking and mulching. A larger number of marketable tubers was produced from staked minisetts and in plots which were established with single rows and mulched than plots established with double rows. It seemed that plants in double row unmulched plots established an adequate crop cover which acted as a mulch and produced yields that were similar to mulched plots. Ferguson (1973) and Oriuma and Onwueme (1980), found that at high plant densities, there was no marked increase in tuber size in D. alata which suggested that the effect of mulching was restricted at the closer spacing. This could explain the significance ininteraction of mulch and spacing in the experiment. These results suggested that the main benefit of plastic mulch was weed control. On the other hand staking increased yield and facilitated other methods of weed control such as hand weeding and the use of herbicides. Total tuber yield was high compared to national average yield of 12t/ha, however, it should be possible to increase marketable yield by increasing the acceptance of tubers weighing less than 1.3kg but are in excess of 0.3kg.

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TABLE I: THE EFFECT OF SETT SIZE ON TOTAL AND MARKETABLE TUBER YIELD (T/HA) FROM YELLOW YAM MINISETTS

	Yield tonnes/hectare		
Sett size	Total	Market 1	Market 2
120g	25.62	23.88	13.14
200g	30.65	27.01	18.92
SED	8.8	15.1	9.1
CV	44.2%	32.9%	21.1%

TABLE II: THE EFFECT OF SETT TYPE ON TOTAL AND MARKETABLE TUBER YIELD (T/HA) FROM YELLOW YAM MINISETTS

	Yield tonnes/hectare		
Sett type	Total	Market 1	Market 2
Head	18.3	14.9	7.0
Middle	19.2	16.5	8.3
Tail	19.7	16.3	7.1
SED	2.48	2.35	1.84
CV	15.8%	18.1%	30.3%

TABLE III: THE EFFECT OF STAKING ON TOTAL AND MARKETABLE TUBER YIELD (T/HA) FROM YELLOW YAM MINISETTS

	Yield tonnes/hectare		
Treatment	Total	Market 1	Market 2
Stake	30.9	28.1	22.3
No stake	21.1	16.9	9.4
SED	1.92	2.31	3.44
C.V.	9.0%	12.6%	26.6%

TABLE IV: THE EFFECT OF MULCHING ON TOTAL AND MARKETABLE TUBER YIELD (T/HA) IN TWO PRODUCTION SYSTEMS FOR YELLOW YAM MINISETTS

Treatment	Yield tonnes/hectare		
	Total	market 1	market 2
Double row mulch	17.86	14.61	7.09
Double row no mulch	21.25	18.31	10.37
Single row mulch	30.67	28.15	16.01
Single row no mulch	22.36	18.35	8.85
SED Row	0.37	2.08	5.55 SED
Mulch	0.82	2.18	4.17
SED Interaction	0.90	3.01	6.94
CV Row	8.3%		
CV Mulch	18.4%		

TABLE V: THE EFFECT OF SETT SIZE ON NUMBER OF MARKETABLE TUBERS FROM YELLOW YAM MINISETTS

Sett size	Number of tubers				
	market 1		market 2		Total
	Umkt	Mkt	Umkt	Mkt	
120 g	75	109	147	37	184
200 g	73	111	131	53	184
Total	148	220	278	90	368

$X^2 = 0.045$ $X^2 = 3.765$

TABLE VI: THE EFFECT OF SETT TYPE ON NUMBER OF MARKETABLE TUBERS FROM YELLOW YAM MINISETTS

Treatment	Number of tubers				
	market 1		market 2		Total
	Umkt	Mkt	Umkt	Mkt	
Head	63	45	93	15	108
Middle	62	57	104	15	119
Tail	56	63	105	14	119
Total	181	165	302	44	346

$X^2=2.888$ $X^2=0.232$

TABLE VII: THE EFFECT OF STAKING ON NUMBER OF MARKETABLE TUBERS FROM YELLOW YAM SETTS

Treatment	Number of tubers				
	market 1		market 2		
	Umkt	Mkt	Umkt	Mkt	Total
Staked	80	102	118	64	182
Unstaked	108	75	157	26	183
Total	188	179	275	90	365

X^2=8.286 X^2=21.573

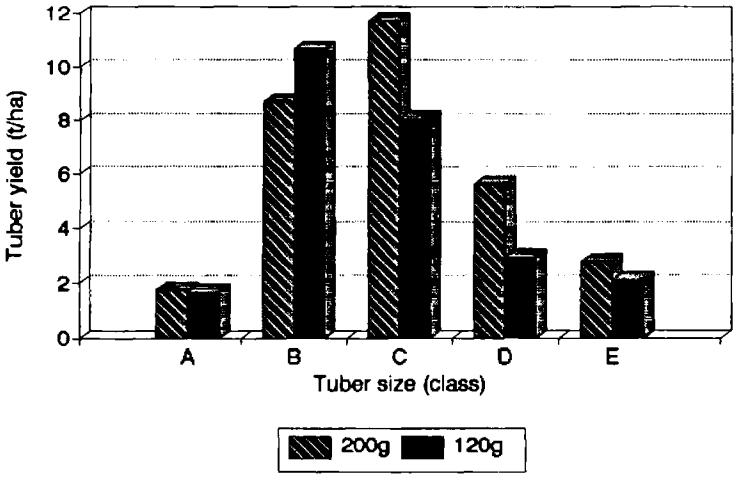
TABLE VIII. THE EFFECT OF MULCHING ON NUMBER OF MARKETABLE TUBERS IN TWO PRODUCTION SYSTEMS FOR YELLOW YAM

Treatment *	Number of tubers				
	market 1		market 2		
	Umkt	Mkt	Umkt	Mkt	Total
Double row mulch	93	65	139	19	158
Double row no mulch	67	74	114	27	141
Single row mulch	67	123	148	42	190
Single row no mulch	96	78	156	18	174
Total	323	340	557	106	663

X^2 =23.256 X^2 =12.315

* Double row mulch -mulched ridges 1.5 m apart planted with two rows.
Double row no mulch - ridges 1.5 m apart planted with two rows (no mulch).
Single row mulch - mulched ridges 0.9 m apart planted with two rows.
Single row no mulch - ridges 0.9 m apart planted with two rows (no mulch).

Fig. 1. Effect of sett size on yield (t/ha) from yellow yam minisetts.



A = 0 - 0.45 kg
B = 0.46 - 0.91 kg
C = 0.92 - 1.36 kg
D = 1.37 - 1.82 kg
E = 1.83 - 2.27 kg
F > 2.27 kg

Fig. 2. Effect of sett type on yield (t/ha) from yellow yam minisetts.

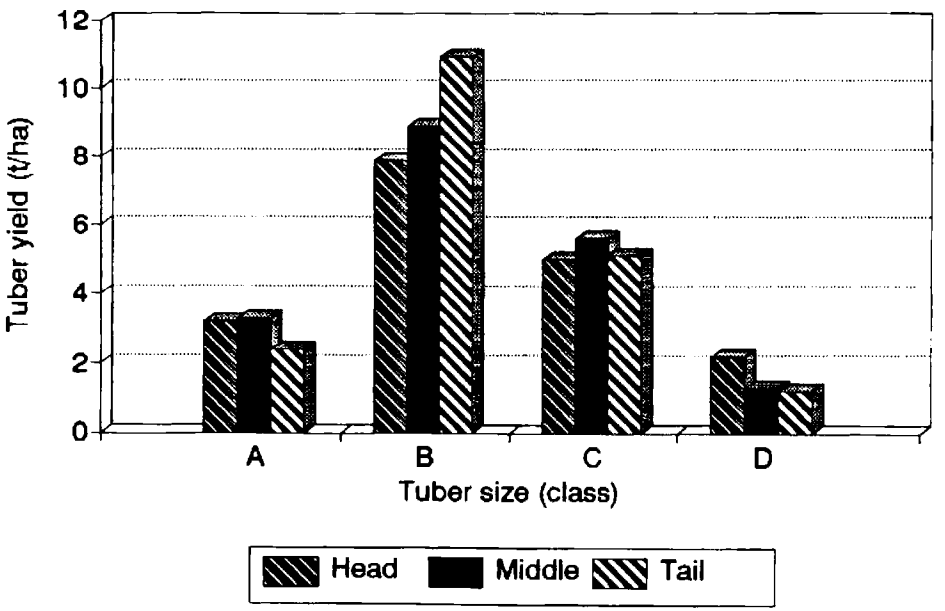


Fig. 3. Effect of staking on tuber yield (t/ha) from yellow yam minisetts.

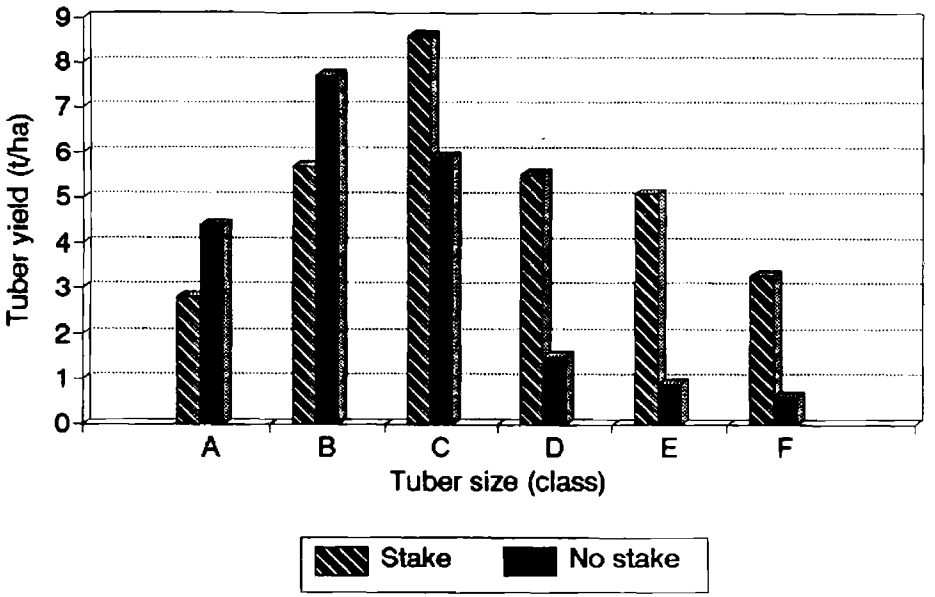
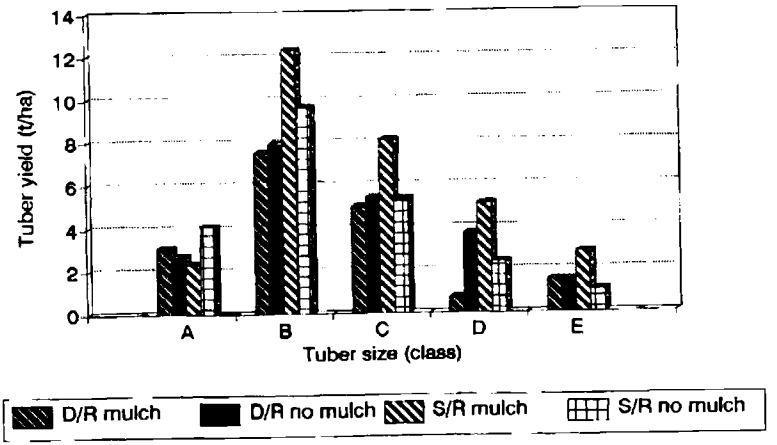


Fig. 4. Effect of mulching on yield (t/ha) in two yam planting systems.



AGRONOMIC COMPARISON AND HCN CONTENT OF THREE CASSAVA CULTIVARS (*MANIHOT ESCULENTA* CRANTZ) IN PUERTO RICO

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ABSTRACT

Three cassava cultivars, Serralles, Sta. Catarina, and Zenon, were field evaluated at nine and 12 months after planting for root tuber yield and hydrocyanic acid potential (HCN-p) on an Oxisol at the ARS Farm, Isabela, Puerto Rico, during 1993-94. Significant differences were found in root tuber yield and HCN-p among cvs. and also in replication x cv. and HCN-p for replications and harvest dates. Sta. Catarina cv. averaged the highest root tuber yield with 31.9 tons/ha, while the Zenon cv. had the lowest HCN-p, 39.1 ppm. Across cvs., there was no significant difference between the two harvest dates in terms of root tuber yield; however, the root tuber HCN-p was significantly lower at the nine-month harvest (45.6 ppm). According to the findings of a taste-testing panel, the root tubers of all three cvs. at the two harvest dates had good culinary quality. However, at nine months, root tubers of the Zenon cv. were considered superior to the other two cvs.; while, at 12 months, those of the Sta. Catarina cv. were slightly preferred by the panel.

INTRODUCTION

In Puerto Rico and in many other tropical countries, cassava (Manihot esculenta Crantz) is a major staple food and a good source of carbohydrates. It is native to tropical America but can be grown in many other areas of the tropics (Purseglove, 1969; Toro and Atlee, 1981; Odigboth, 1983; Ramírez et al., 1983; and Cárdenas and Vázquez, 1990). Cassava can be cultivated in soils of low fertility and low pH and has tolerance to insects, diseases, and drought.

Throughout the world, approximately 15.7 million hectares of cassava are under cultivation, representing 33% of the total area devoted to root and tuber crops (47.2 million hectares). Sweet potatoes constitute 20% (9.3 million hectares), and yams, 6% (2.6). World production of roots and tubers is 574.6 million tons, and cassava production accounts for 153.7 million tons (27% of the total). According to FAO, the country with the highest cassava production in 1991 was Brazil (24.6 million tons), followed by Thailand (20.3), Nigeria (20.0), Zaire (18.2), and Indonesia (16.3). In the Caribbean, less cassava is generally grown than in other areas of the tropics. The main producer is Cuba (7,200 hectares and 0.3 million tons) followed by Haiti (6,800 hectares and 0.29 million tons) (FAO, 1992).

In Puerto Rico, cassava production has declined in recent years, while importations of the root crop have increased. During 1975, 3909 tons were produced locally, and 709 tons were imported. This trend has continued up to the present time (Fig. 1). During 1991, 2,545 tons of cassava were produced, with a farm gate value of $987,840, and 2,287 tons (47%) were imported. In 1993, only 1,591 tons were produced locally, with a farm gate value of $542,850, and 2,328 tons (59%) were imported. The local price of cassava in 1993 was $341/ton at the farm gate as compared to yams ($682/ton) and sweet potatoes ($396/ton) (Ortiz, 1994).

Cassava is usually planted in Puerto Rico during April and May and harvested approximately 10 months after. Most of the acreage devoted to cassava is located in the northwestern part of the island in the Isabela area.

In the past five years, the USDA, ARS Tropical Agriculture Research Station (TARS), Mayaguez, Puerto Rico, has evaluated more than 50 introductions of cassava for high yield, low HCN-p, and good culinary quality. Two cassava cvs. from the TARS collection (Serralles and Sta. Catarina)

that were found to be superior in previous trials (Cárdenas and Vázquez, 1990; Cárdenas et al., 1991) were compared in a field evaluation with the Zenon cv. recently introduced from the Dominican Republic.

These cvs. were evaluated for yield, HCN-p, and culinary quality at nine and 12 months after planting.

MATERIALS AND METHODS

The experiment was conducted at the Isabela ARS Farm. Table 1 provides information on weather data and the general characteristics of the experiment site. Throughout the experiment, the temperature ranged from 21.9 to 32.8° C, and total rainfall was 1,031 mm.

The growth pattern of all cvs. was similar. The root tubers of the Serralles and Zenon cvs. were alike in shape and color with brown skin and white flesh, while those of Sta. Catarina had light-brown skin and cream-colored flesh.

The experimental design was a complete randomized block with an arrangement of a split plot with four replications. Cultivars were the main plots and harvest dates the subplots. Plots consisted of 20 cuttings 15-20 cm long of each cv. planted in two rows (10 plants per row) 10 m long and one m apart. Weed control was done by hand, and plots were sprinkler irrigated when needed. No fertilizer or pesticides were applied.

On December 15, 1993, and March 15, 1994, (nine and 12 months after planting), the cassava cvs. were harvested using a 24 hp Farmall International tractor and a special system devised at the Isabela Farm which consisted of a chain and a piece of metal attached to the PTO of the tractor to pull the root tubers out of the ground.

The root tubers were cleaned and weighed in the field, and root samples were immediately taken to the TARS laboratory for HCN-p determination. The analysis was performed using the rapid method recommended by CIAT (CIAT, 1984), which involves the use of picric acid, sodium carbonate, and toluene. Five drops of toluene were added to one g of fresh root tuber sample. An alkaline-picric acid strip was put in the vial containing the sample for a 24-hour period. The strip color was read against a color chart prepared by CIAT. The color ranged from yellow (low HCN-p) to dark red (high HCN-p). Four persons from TARS were selected for the taste-testing panel to evaluate the culinary quality of the root tubers of the three cvs. at the two harvest dates.

RESULTS AND DISCUSSION

Regardless of plant maturity at harvest, the Sta. Catarina cv. significantly out yielded the Serralles and Zenon cvs., with an average production of 31.9 tons/hectare (Table 2). The three-month harvest delay did not significantly increase yield.

Previous experiments with the Sta. Catarina cv. grown in an Oxisol at the Isabela Farm resulted in average yields of 20.7 tons/ha (Cárdenas and Vázquez, 1990) and in an Ultisol soil at Corozal, Puerto Rico, 24.3 tons/ha (Ramírez et al., 1983). There was a significant difference between Zenon and the other two cvs. for root tuber HCN-p, Zenon having the lowest level, 39.1 ppm (Table 2). The delay in harvest did not affect the HCN-p of the cvs. These HCN-p findings are in accord with previously reported levels (Ramírez et al., 1983; Cárdenas et al., 1991).

The culinary quality of the cooked root tubers for all cvs. were classified as having good taste and texture, although nine-month-old root tubers of the Zenon cv. were considered superior and those of Sta. Catarina were slightly preferred at the 12-month harvest. On the basis of yield, HCN-p, and culinary quality, all three cassava cvs. are recommended for commercial production in Puerto Rico and the tropics in general. Throughout the experiment, root tubers of the Zenon cv. were damaged by rodents, thereby reducing their yield. This may have been due to the lower HCN-p in the root tubers of this cv. Since there was no significant difference in yield between harvest dates, it is recommended that these cvs. be harvested at nine months after planting.

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Table 1. Description of the experiment site for the field evaluation of the three cassava cultivars.

Location	Isabela, Puerto Rico
Latitude	18° 30' N
Longitude	67° W
Temperature range	18.8° - 29.4° C
Elevation	128 m
Annual rainfall	1,675 mm
Soil	Oxisol (Coto)
Organic matter	2.5%
Exchange capacity	23 meq/100 g soil
pH	5.0
P (ppm)	53
K (ppm)	140
NO_3 (ppm)	10

Table 2. Root tuber yield and HCN-p of three cassava cultivars harvested at nine and 12 months after planting at Isabela, Puerto Rico during 1993-94.

Character						
	Yield (tons/ha) Months			HCN-p (ppm) Months		
Cultivar	Nine	Twelve	X	Nine	Twelve	X
Serrallés	24.89 b[1/]	25.13 b	25.01 b	51.25 a	52.50 a	51.87 a
Sta. Catarina	32.75 a	31.00 a	31.87 a	51.88 a	52.50 a	52.19 a
Zenón	21.38 b	25.13 b	23.25 b	33.75 b	44.38 b	39.06 b
X	26.34 a	27.09 a		45.63 a	49.79 a	

[1/] Means followed by the same letter within rows or within columns are not significantly different (P>0.05) based on an LSD test.

DRYING OF THE DASHEEN LEAF

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ABSTRACT

The drying behavior of the dasheen leaf under natural convection conditions at temperatures ranging from 40-70°C was studied in an attempt to develop a dehydrated product from this popular vegetable often used in soups and commonly called - 'callaloo.' The effects of various pretreatments on the drying behavioral of the vegetable at 60°C were also studied, viz. steam blanching (96°C for 6 min.), water blanching (near boiling for 10s) and blanching in 0.06% magnesium carbonate at near boiling for 10 s prior to immersion in a mixed chemical bath consisting mainly of 20% sucrose, for 4 h at 21°C. Two falling rate periods of drying were observed for dasheen leaves dried at 40-70°C. However, a single falling rate period of drying was found for the water and magnesium carbonate blanched-infused vegetable at 60°C. Although drying rates markedly increased with increasing drying temperature, drying at high temperatures particularly at 60°C and 70°C resulted in a deleterious color change from green, typical of the fresh vegetable, to an unattractive olive-brown or brown discoloration. Steam blanching appeared to have no significant effect on the drying rate of the dasheen leaf compared to fresh leaves while for the water blanched vegetable, the drying rate was reduced by 50%. Compared to water blanching, alkali blanching was found to have no significant effect on the drying rate of the dasheen leaf. Blanching in water or alkali resulted in a superior dehydrated product which, unlike the steam blanched vegetable, showed minimal loss of green color.

INTRODUCTION

The dasheen (*Colocasia esculenta* Linn Schott var *esculenta*)is a herbaceous, tuberous perennial with distinctively large leaves. It is cultivated extensively in tropical countries like Trinidad and Tobago, for both the tender leaves and the tubers. Commonly referred to as "dasheen bush" or "callaloo bush" in Trinidad and Tobago, or "taro" by the English, this leafy vegetable has considerable export market potential to immigrant West Indian populations in U.S.A., Canada and Europe (Harvey, 1986). The fresh vegetable is currently exported from Trinidad and Tobago to New York and London. Dasheen leaves however, like all leafy horticultural commodities have high transpiration rates due to their large surface area to volume ratio and thus wilt rapidly under ambient conditions. Consequently, leaf senescence and the attendant decline in post harvest quality e.g. loss of green color and loss of nutritional value is accelerated (Lazan et al., 1987). As a result, the fresh vegetable must be air freighted immediately after harvest.

A possible alternative to the export of the fresh vegetable is the export of a dehydrated product which can be used like spinach in soups, casseroles etc. Dehydration, a simple method of preserving foods to extend their period of availability, has the added advantage of making handling, storage and distribution less difficult and more economical because of reduction in weight and bulk.

There is considerable information on the drying of similar foliaceous type materials. Chen and Johnson (1969) reported the absence of a constant rate period of drying when tobacco laminae was dried at temperatures ranging from 30-50°C. Menzies and O'Callaghan (1971) in their study on the effect of drying temperature on the drying behavior of high moisture grass noted: (i) the "constant rate" period of drying occurred above 200°C and (ii) below 200°C, drying took place

in the "falling rate" period essentially through the diffusion mechanism. Below 80°C, up to 3 distinct periods of falling rate drying was found.

For drying in the falling rate period, where the mechanism of moisture removal within the vegetable to the surface is by a diffusional process, the exponential relationship normally used to describe the drying behavior of similar biological materials (Menzies and O'Callaghan, 1971; Rotz and Chen, 1985), is of the form:

$$(m - me)/(mo - mc) = Ac\text{-}kt \quad \ldots\ldots (1)$$

or in the logarithmic form

$$\ln[(m - me)/(mo - me)] = \ln A\text{-}kt \quad \ldots\ldots (2)$$

where

m	=	variable moisture content, % dry basis
me	=	equilibrium moisture content, % dry basis
mo	=	initial moisture content, % dry basis
k	=	drying constant, h-1
t	=	drying time, h
A	=	constant

Loss of green color and other quality changes, eg loss of Vitamin C (ascorbic acid) are reported to occur during the dehydration of green commodities (Morgan et al., 1945; Weits et al., 1970; Ranganath and Dubash, 1981). The principal degradatory pathway of chlorophyll in the dehydration of green vegetables is the replacement of its magnesium atom by hydrogen and the consequent formation of olive-brown pheophytins (MacKinney and Weast, 1940; Clydesdale et al., 1970; Davidek et al., 1990). The necessity of blanching vegetables prior to dehydration has been recognized since 1929 (Dietrich et al., 1955). MacKinney and Weast (1940) and von Loesecke (1955) stated that blanching was necessary to prevent the formation of off-flavors, odors and colors. Peroxidase activity is widely used as an index of blanching as it is the most heat stable enzyme found in vegetables. Blanching however, is reported to result in some degree of chlorophyll degradation with the subsequent formation of pheophytin. The extent of chlorophyll conversion being related to the degree of blanching (MacKinney and Weast, 1940; Dutton et al., 1943; Lee 1958). Loss of ascorbic acid is also claimed to occur during the blanching process (Farrell and Fellers, 1942; Kincal and Giray, 1987). Considerable effort has been aimed at stabilizing the color of green vegetables during thermal processing. The most widely reported method for the prevention of pheophytin formation is the addition of alkalizing agents e.g. magnesium carbonate (Lioutas, 1989).

The objectives of this study were:

(1) To determine the drying characteristics and quality of dasheen leaves at air drying temperatures of 40, 50, 60 and 70°C.

(2) To determine the drying characteristics and quality of dasheen leaves at 60°C after blanching in steam, water and alkali-infusion.

MATERIALS AND METHODS

Experimental Design

A. Approximately 20 kg of the fresh, green vegetable was obtained from farmers' holdings

situated in Central Trinidad. The harvested vegetable was washed, destalked and chopped using a Chuo Boeki Goshi Kaisha Forage Cutter Model No. FC13B at a speed of 850 r.p.m. The vegetable pieces were kept in a sealed polyethylene bag at 10°C until required. 400 g of the chopped vegetable was placed to a depth of 0.034 m in a wire meshed tray (0.38 by 0.4 m) in dimensions and dried to constant weight at 40°C in a natural convection oven (Blue M Stabil Therm Gravity Oven). At hourly intervals except during the night , the tray was removed, quickly weighed and drying continued until there was virtually no change in weight. The drying was repeated using 400 g samples of the chopped vegetable at temperatures of 50, 60 and 70°C.

B. The effect of various pre-drying treatments on the drying behavior and quality of dasheen leaves at 60°C was also investigated. Pre-drying treatments investigated were steam and water blanching, and blanching in alkali followed by infusion in a chemical bath of which the main constituent was sucrose. The blanch times used were sufficient to inactivate the enzymeperoxidase. The shortest blanch time for each method was pre-determined by the peroxidase test outlined by Greensmith (1971). The untreated vegetable served as a con trol.

Steam blanching

400 g of chopped dasheen leaves was blanched in steam at 96°C, 100 psi for 6 min, and cooled under ambient conditions (28°C). 326 g was placed in a gravity oven at 60°C for evaluation of its drying characteristics.

Water blanching

400 g chopped dasheen leaves was immersed in water at 100°C for 10 sec, cooled and allowed to drain for 2 min. 326 g was placed in a gravity oven at 60°C for examination of the drying behavior of the water blanched vegetable.

Chemical treatment

400 g of the chopped vegetable was blanched for 10 sec in hot water at 100°C containing 0.06% magnesium carbonate. The blanched vegetable was allowed to cool before infusion for 4 hours at 21°C in an aqueous infusion bath (5:1 ratio of bath to vegetable) comprising of sucrose - 20%, sodium chloride - 3%, potassium chloride - 0.37%, magnesium carbonate - 0.37%, disodium phosphate - 0.9%, monosodium phosphate - 0.05%, lecithin - 0.5%, tocopherol - 0.05%. After infusion the vegetable was drained and 326 g was dried at 60°C.

Control (untreated)

326 g of the chopped vegetable was placed in a gravity oven at 60°C for evaluation of its drying characteristics.

For all treatments investigated, weights were taken at half hour intervals for the first three hours of drying and as drying progressed intervals increased to one hour.

Measurements

Freshly harvested dasheen leaves as well as the dehydrated products were analyzed for ascorbic acid, chlorophyll, phoephytin, pH and moisture content. Analyses were carried out in duplicate and the resulting data analyzed by the Analysis of Variance Method (ANOVA).

Ascorbic acid in fresh and dehydrated dasheen leaves were extracted and assayed according to the 2, 6 - dichlorophenol indophenol visual titration method of Ranganna (1977). Chlorophyll and pheophytin levels were evaluated by the spectrophotometric method of Vernon (1960) modified by Berset and Caniaus (1983). For pH determination, 5 and 2 g samples of the fresh and dried (ground) vegetable respectively were blended with 40 ml of distilled water. For moisture content, 50 and 10 g samples of fresh and dehydrated dasheen leaves respectively were placed at 105 ¡C in a forced-draft oven for 16 h.

RESULTS AND DISCUSSION

Drying Characteristics of the Dasheen Leaf - Effect of temperature

Figures 1 to 3 show the drying behaviour of the dasheen leaf under natural convection conditions at air temperatures ranging from 40-70°C. A nonuniform decrease in the drying rate was observed as the air drying temperature was lowered (Figure 2). The drying curve at 40°C (Figure 1) was the least steep and spaced further apart relative to those at the other three temperatures investigated. This indicates the positive influence of increasing the temperature on the drying rate of this leafy vegetable over the temperature range 40-70°C.

Drying times markedly decreased with increasing drying temperature, near equilibrium being achieved after 56, 24, 24 and 12 h at 40, 50, 60 and 70°C respectively, with the corresponding final moisture contents of 6.2, 2.5, 3.1 and 1.9% d.b. Plots at 50 and 60°C showed near similar drying behavior and this may have been due to temperature fluctuations in the drying chamber at 50°C only.

Figure 2 shows the absence of a constant rate period of drying, an indication that the rate of moisture evaporation from the surface of the vegetable to the surrounding air was not constant and that the drying rate is internally controlled. The entire drying process for dasheen leaves under natural convection conditions as shown in the Figure, occurs exclusively in the range of the falling rate period.

Fitting the drying data to equation (2), through linear regression analyses yielded correlation coefficients (Figure 3) of the order of $0.850 < R^2 < 0.960$, indicative of a non linear trend in drying. This suggests the inadequacy of a single falling rate period or equation in describing the drying behaviour of dasheen leaves under natural convection conditions. Separation of the drying data into two distinct periods of drying yielded better fits (Figure 4). Transition times of 12.0, 6.0, 6.5 and 2.5 h with corresponding moisture contents of 220.8, 122.3, 154.8 and 320.0% d.b (wet basis range from 55.0-76.2%) were found for the vegetable at air drying temperatures of 40, 50, 60 and 70°C respectively.

Examination of Figure 4 reveals an unusual feature in the drying behaviour of the dasheen leaf. It appears that irrespective of drying temperature, drying proceeds via a relatively short initial phase which is immediately followed by a longer second period having a rate constant higher than the first period of drying i.e $k_2 > k_1$. The initial phase of drying is thought of as an initial "warm up" period and corresponds to the time required for the vegetable to attain or closely approximate the desired drying temperature upon placement in the drying chamber, at which point, the drying rate is increased. The second phase of drying can be considered as the "true" falling rate period. The temperature profiles at 50°C and 70°C (Figure 5) show considerable fluctuation during the early stages of drying i.e. before near attainment of the air dry bulb temperature by the vegetable. This was due to the accumulation of moisture within the bed and around the probe thus accounting for the aberrant drying rates observed. Clearly therefore k_2 values were higher than k_1; because the cropÔs temperature was higher in the latter period of drying.

Drying Characteristics of the Dasheen Leaf - Effect of Pre-drying Treatments

Figures 6 to 8 show the effect of various pre-drying treatments on the drying behaviour under natural convection of dasheen leaves at 60°C. Equilibrium moisture contents expressed on a dry basis were 1.2% for both the steam and water blanched vegetable, occurring after 6 and 8 h of drying respectively. For the magnesium carbonate blanched-infused and untreated (control) vegetable, equilibrium moisture contents were 1.3 and 2.5% d.b respectively occurring after 8 and 7 h of drying respectively.

As shown in Figure 7 drying occurred solely in the range of the falling rate period. Figure 8 shows a linear trend in the drying behavior of the water blanched and magnesium carbonate blanched-infused vegetable with correlation coefficients of 0.996 and 0.995 respectively suggesting that drying is characterized by a single falling rate period. The semilogarithmic plots for both the steam blanched and control (untreated) vegetable (Figure 8) yielded relatively lower correlation coefficients when the drying data was fitted to equation 2. As shown in Figure 9, separation of the data into two periods of drying at transition times of 1.8 and 1.6 h corresponding to critical moisture contents of 200.5 and 201.2 % d.b for the control (untreated) and steam blanched vegetable respectively resulted in good fits. As observed for the fresh vegetable dried at temperatures ranging from 40-70°C, k_2 the rate constant for the second phase of drying was found to be greater than k_1, the rate constant for the first period of drying for both the control (untreated) and steam blanched dehydrated vegetable. The absence of two falling rate periods of drying for water and magnesium carbonate blanched-infused dasheen leaves is probably due to structural changes occurring during heat processing. Dasheen leaves appearing soggy and very soft subsequent to blanching in water and magnesium carbonate. Under these conditions moisture movement during drying may be occurring through capillary action rather than diffusion.

Steam blanching appears to have no significant effect on the rate of moisture removal from the dasheen leaf when compared to the control (untreated) vegetable as differences in drying rates were marginal. As shown in Figure 9, k_1 for the steam blanched and untreated vegetable were 0.562 and 0.550 h^{-1} respectively with corresponding k_2 values of 1.967 and 1.528 h^{-1}.

Both the water blanched and alkali blanched-infused vegetable showed a 50% reduction in drying rate when compared to the control (untreated) dried vegetable. Unlike the steam blanched sample which showed a negligible change in moisture content subsequent to blanching, the moisture content of the vegetable approximately doubled after water blanching probably accounting for the net reduced drying rate observed. Differences in drying rates between the magnesium carbonate blanched-infused vegetable and the untreated (control) may be ascribed to the increased total soluble solids content which tripled following infusion.

Quality Evaluation of Dehydrated Dasheen Leaf - Effect of Temperature

Ascorbic acid

The ascorbic acid (vitamin C) content in fresh and dehydrated dasheen leaves is shown in Table 1. The data represents mean values from two observations. A considerable decline from an initial value of 494 mg/100g DM ($P < 0.001$) for the green, freshly harvested vegetable occurred during the drying process, losses ranging from 91.6-93.9% for the vegetable at air drying temperatures of 40-70°C. As shown in Table 1, changes in drying temperature did not markedly influence ascorbic acid losses. This suggests that drying to near equilibrium at the temperatures investigated was sufficient to bring about an almost complete destruction of the vitamin.

Color, pigment and pH changes

Dramatic visual changes in color from green, typical of freshly harvested dasheen leaves to

olive-green and olive-brown occurred as the air drying temperature increased from 40-70 °C. Such undesirable color changes reflect the marked reduction in the chlorophyll content ($P < 0.001$), the pigment responsible for the characteristic green color of the vegetable, from an initial value of 1262 mg/100g DM with increasing drying temperature (Table 1).

Concomitant with the acceleration in chlorophyll degradation, an increase ($P < 0.01$) in pheophytin content was observed with increasing drying temperature (Table 1). There was also a significant decline in pH ($P < 0.001$) from 6.4 for fresh, green dasheen leaves. Chlorophyll and pheophytin contents of the vegetable dried at 40°C to a moisture content of 6.2% d.b, were 953 and 232 mg/100g DM respectively. The dehydrated vegetable, with a pH of 5.8, appeared olive-green showing very little signs of browning. For the vegetable dried at 70°C however, a marked increase in acidity (pH of 4.7) was noted, and loss in green color was severe, reflected by a retention of only 2.8% of its initial chlorophyll content. These deteriorative changes were paralleled by extensive browning of the dried product, consistent with an increase in pheophytin content to 813 mg/100g DM.

The results of this study are supported by the works of Sweeney and Martin (1961), Hudson et al. (1974) and Lioutas (1989) who found that chlorophyll is converted to pheophytin at acidic pH's. The negative correlation observed between chlorophyll and pheophytin concentrations, which increased progressively with air drying temperature is ascribed not only to increased acid formation but also increased susceptibility of chlorophyll to acid action (Meyer, 1960; Davidek et al., 1990).

Quality Evaluation of Dehydrated Dasheen Leaf - Effect of Pre-drying Treatments

Ascorbic acid

Irrespective of pre-drying treatments, a significant decline ($P < 0.001$) in the ascorbic acid content from an initial value of 581 mg/100g DM was found for dasheen leaves dried at 60¡C (Table 2). The ascorbic acid content of control (untreated) dehydrated dasheen leaves was 66 mg/100g DM, representing a severe loss of 89% of its initial vitamin content due to thermal and possibly enzymic degradation. The effects of blanching in magnesium carbonate followed by infusion in a bath comprising mainly of 20% sucrose on the ascorbic acid content of the dehydrated vegetable was more pronounced, resulting in a substantial loss of 98%. This is attributable to the combined effects of thermal degradation and leaching during blanching and osmosis (Farrel and Fellers, 1942; Morgan et al., 1945; Islam and Flink, 1982).

Blanching in steam and water prior to dehydration resulted in ascorbic acid contents of 22 and 45 mg/100g DM respectively . The results of this study highlight the severity of the heat treatment employed in steam blanching i.e 98°C for 6 mins compared to the quick blanch (10 secs at 100°C) used in water blanching, which, though adequate for the inactivation of enzymes, adversely affected the ascorbic acid content of the vegetable. Disruption of cells, claimed to occur during steam blanching, is reported to enhance loss of ascorbic acid (Philippon, 1985).

Color, pigment and pH changes

The pre-drying treatments investigated greatly affected the pH of the dehydrated vegetable, which in turn, directly influenced color and hence pigment (chlorophyll and pheophytin) concentrations (Table 2). Untreated dehydrated dasheen leaves declined significantly in pH ($P < 0.001$) from 6.3 for the fresh, green vegetable to 5.8. The dehydrated vegetable, dull green to olive-brown in color and with a pheophytin concentration of 400 mg/100g DM showed a marked decline in chlorophyll content ($P < 0.001$) from 1091 mg/100g DM for fresh dasheen leaves to 668 mg/100g DM.

For equivalent peroxidase inactivation, blanching in steam resulted in enhanced chlorophyll loss paralleled by increased pheophytin formation in the dehydrated vegetable compared to pre-drying treatments of blanching in water or alkali-infusion (Table 2). Steam blanched dehydrated dasheen leaves, with a pH of 5.6, olive-green to olive-brown in color, reflected a substantial chlorophyll loss

of 58% and a high pheophytin content of 695 mg/100g DM.

The water blanched dehydrated vegetable, with a pH of 6.5 and a chlorophyll content of 816 mg/100g DM, corresponding to a loss of 25%, was attractively bright green in color. The dehydrated vegetable showed no signs of browning, however, darkening in the veinal region, typical of the fresh vegetable became prominent following dehydration.

Loss of green color was significantly reduced in the dehydrated vegetable following alkali blanching-infusion. The dehydrated vegetable, with a pH of 7.3 exhibited a chlorophyll loss of 31% and like the water blanched dehydrated vegetable showed no signs of browning. Lioutas (1989) found excellent color stability when broccoli was similarly treated and dehydrated at 110°F (44°C). This author claimed a pH of 7-9 to be crucial in chlorophyll retention since alkali salts prevent or minimize pheophytin formation by neutralizing plant acids released or formed during heat processing. The loss of chlorophyll observed for water and alkali blanched-infused dehydrated vegetable in the absence of pheophytin formation suggests other methods of chlorophyll degradation eg allomerisation of chlorophyll, rupture of the tetrapyrrole ring to form chlorins and purpurins etc.(Clydesdale et al., 1970).

CONCLUSIONS

Drying of fresh dasheen leaves under natural convection at temperatures ranging from 40-70¡C occurred principally in the range of the falling rate period and the total drying period can be divided into 2 falling rate periods of drying. Increasing air drying temperature enhanced loss in green color, concomitant with increased pheophytin formation and was paralleled by a significant decline in pH. Irrespective of air drying temperature, losses in ascorbic acid were high ranging from 91.6 - 93.9 % for the vegetable at air drying temperatures of 40 - 70°C.

Compared to the untreated dehydrated vegetable at 60°C, blanching in steam did not markedly alter the drying rate, both products of dehydration appearing olive-green to olive-brown in color. Blanching in water or magnesium carbonate-infusion appeared to have altered the physical properties of the vegetable as single falling rate periods of drying were distinguished. Water and alkali blanching-infusion, while enhancing ascorbic acid losses, yielded superior dehydrated products showing minimum losses in green color with no signs of browning.

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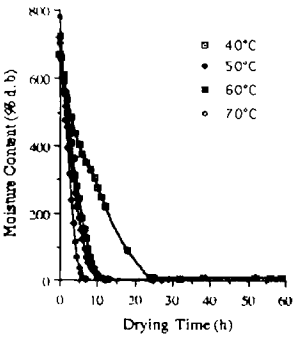


Fig 1 : Drying curves for dasheen leaf at four temperatures

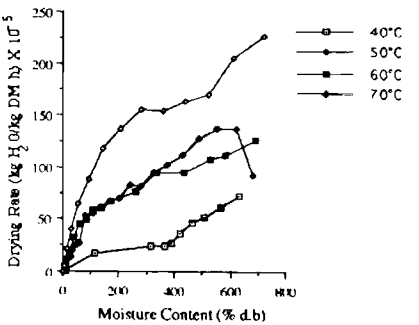


Fig 2 : Drying rate curves for dasheen leaf at four temperatures

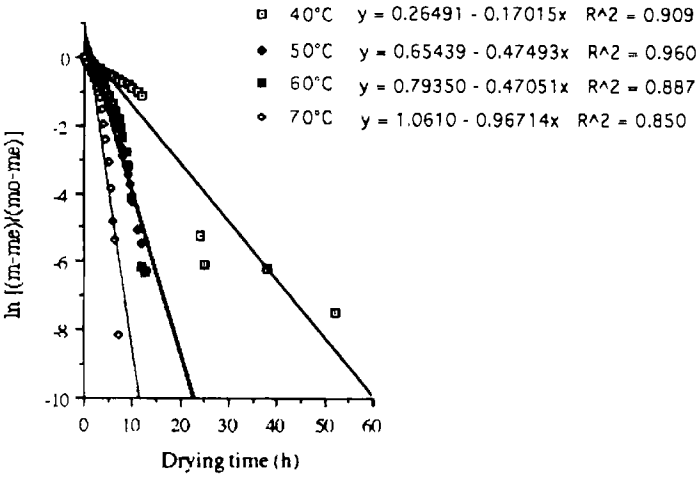
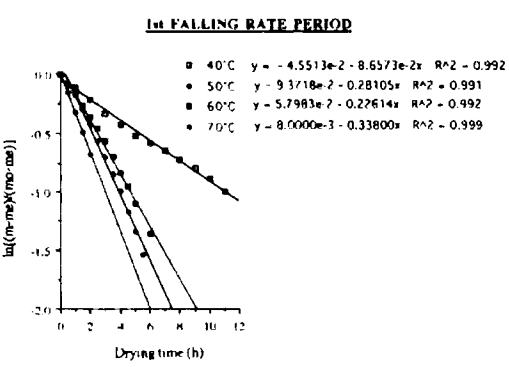


FIG 3 : Semi-logarithmic plots for dasheen leaves at four temperatures



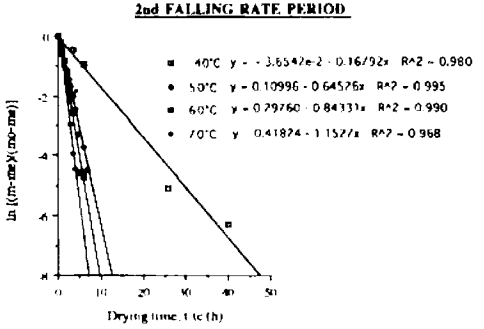


Fig 4 : Semi-logarithmic plots for first and second falling rate periods of drying of dasheen leaf at four temperatures

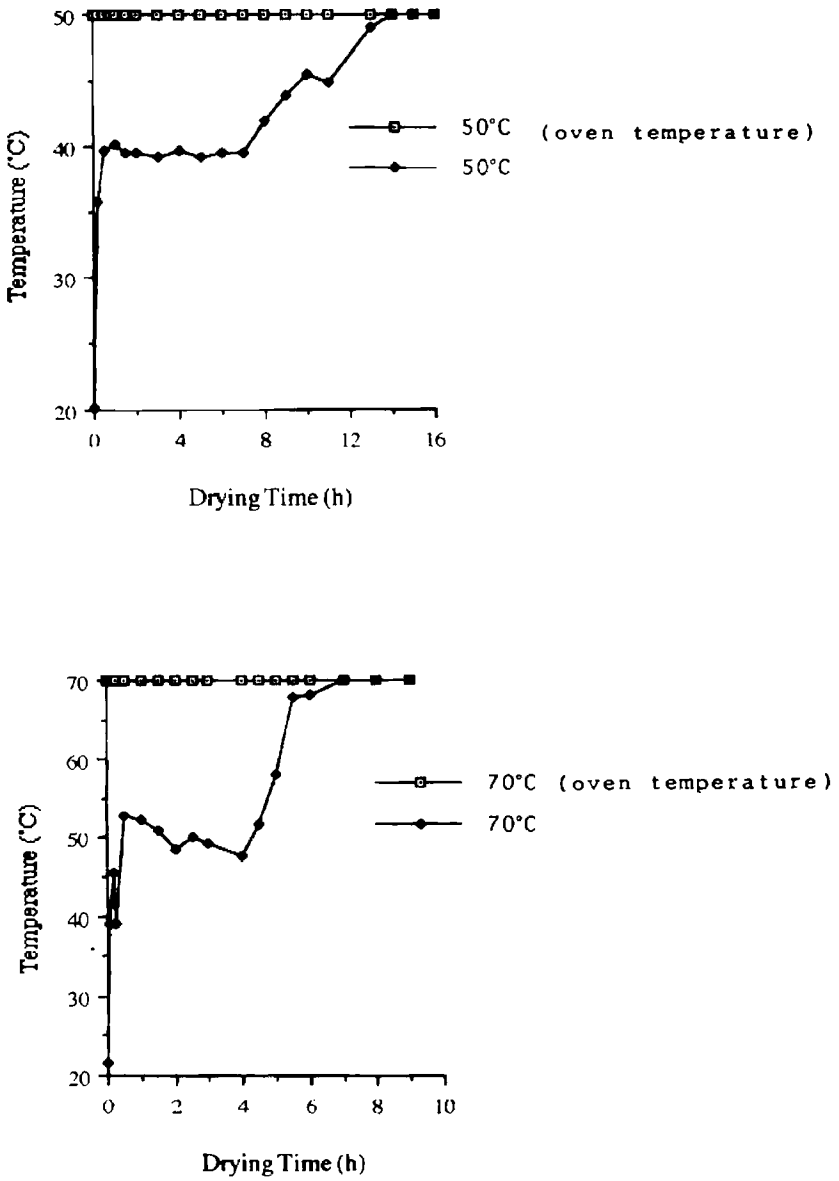


Fig 5 : Temperature profiles of dasheen leaf at 50°C and 70°C

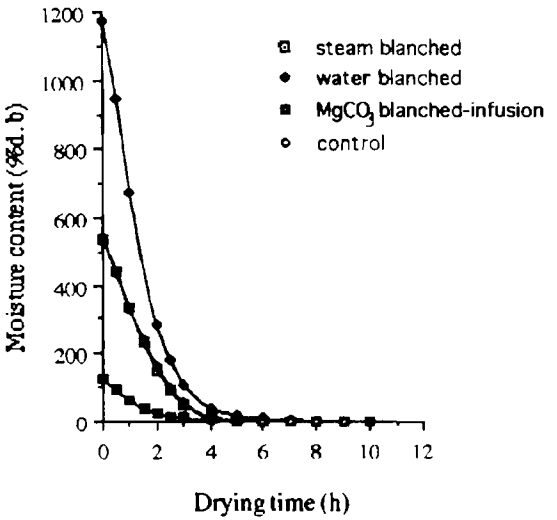


Fig 6 : Drying curves of treated and untreated dasheen leaf dried at 60°C

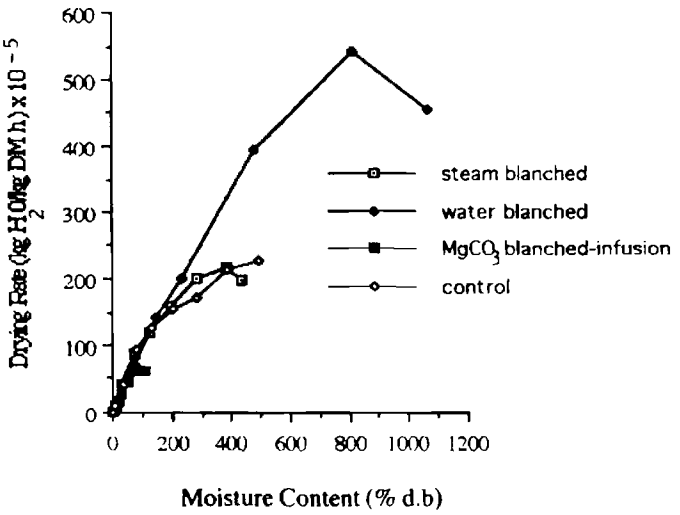


Fig 7: Drying rate curves of treated and untreated dasheen leaf dried at 60°C

▫	steam blanched	y = 1.0003 - 1.4319x R^2 = 0.867
◆	water blanched	y = 0.16663 - 0.85246x R^2 = 0.996
▪	$MgCO_3$ blanched-infusion	y = - 4.5356e-3 - 0.81077x R^2 = 0.995
◇	control	y = 0.79326 - 1.2499x R^2 = 0.956

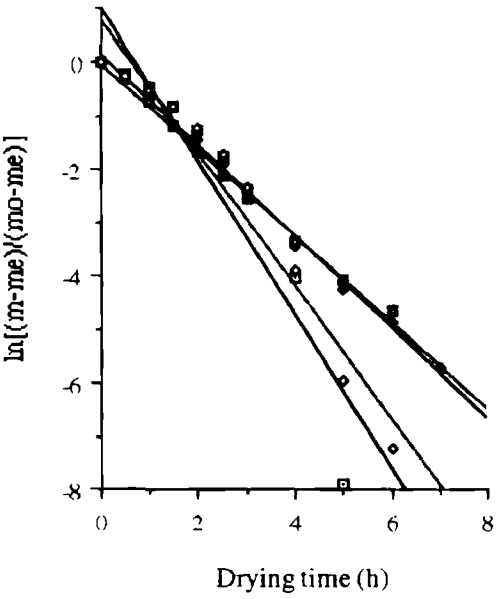
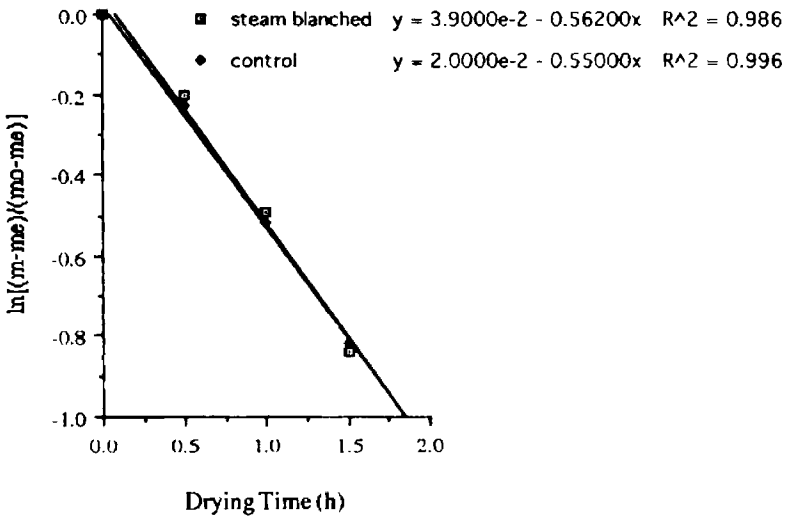


Fig 8 : Semi-logarithmic plots of treated and untreated dasheen leaf dried at 60°C

Ist FALLING RATE PERIOD



2nd FALLING RATE PERIOD

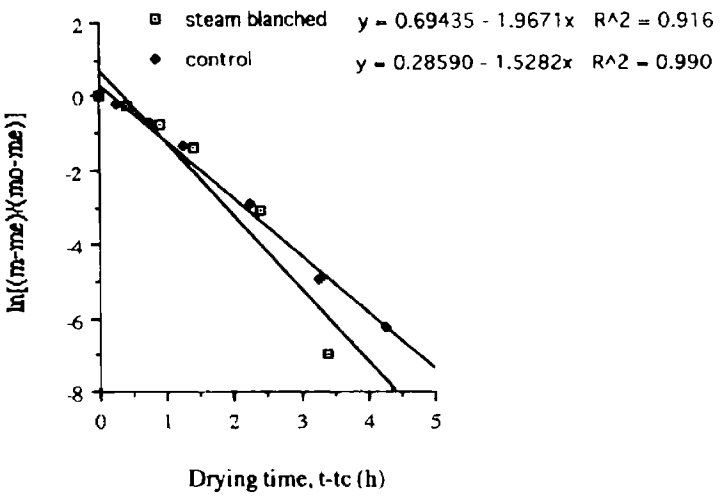


Fig 9 : Semi-logarithmic plots for first and second falling rate periods of drying of treated and untreated dasheen leaf dried at 60°C

Table 1. Chemical properties of fresh and dried dasheen leaf

Product	[a]Ascorbic Acid (mg/100 g DM)	[a]Chlorophyll (mg/100 g DM)	[a]Pheophytin (mg/100 g DM)	[a]pH
Fresh	494	1262	0	6.4
Dried (°C)				
40	34	953	232	5.8
50	30	523	541	5.6
60	42	83	797	4.7
70	40	35	813	4.7

[a] denotes the mean of 2 replications

Table 2. Chemical properties of fresh and dried dasheen leaves subjected to various pre-drying treatments prior to drying at 60°C.

Product	[a]Ascorbic Acid (mg/100 g DM)	[a]Chlorophyll (mg/100 g DM)	[a]Pheophytin (mg/100 g DM)	[a]pH
Fresh	581	1091	0	6.3
Dried				
Steam blanched	22	486	695	5.6
Water blanched	45	816	0	6.5
$MgCO_3$ blanched infusion	13	751	0	7.3
Control	66	668	400	5.8

[a] denotes the mean of 2 replications

AQUAPONICS: THE INTEGRATION OF FISH AND VEGETABLE CULTURE IN RECIRCULATING SYSTEMS

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ABSTRACT

A commercial-scale, aquaponic system for the intensive production of tilapia and hydroponic vegetables has been developed at the Virgin Islands Agricultural Experiment Station. The system is well suited for Caribbean islands and other tropical regions where fresh water is scarce or level farm land is limited. It consists of a fish rearing tank, a clarifier, two hydroponic tanks and a reservoir, and is reliable, productive and easy to operate. Water continuously circulates between the fish and hydroponic components. The fish grow rapidly on a pelleted diet that is high in protein. Waste from the fish provides most of the nutrients required by vegetables. The vegetables recover these nutrients as a valuable by-product and purify the water. The presence of both fish and plants creates a very stable growing environment, while high nutrient levels and unlimited water promote rapid vegetable growth. This system is economical because nutrient costs are reduced, the need for expensive filtration devices is eliminated, component operating and infrastructural costs are shared, land requirements are small, water is conserved, and environmental impacts are minimized.

INTRODUCTION

Field crop production and aquaculture potential on many Caribbean islands are hindered by rugged topography or insufficient water resources. As a consequence, large quantities of food must be purchased abroad with considerable impact on fragile island economies. For example, the Lesser Antilles imported 16,500 mt of fish and fish products in 1987 at a cost of U.S. $56 million (FAO, 1987). Alternative production systems are needed to boost local food supplies and retain foreign exchange.

The University of the Virgin Islands (UVI) Agricultural Experiment Station has taken a new approach to growing more food by integrating vegetable hydroponics with fish culture in recirculating systems, a technology that is being called aquaponics. These diverse agricultural enterprises are being combined to increase production while minimizing nutrient inputs and the consumption of water.

In fish culture, only a minor proportion (25-30%) of nutrients applied in the form of feed are retained by fish as weight gain. The remaining nutrients are excreted in solid and dissolved forms. Dissolved nutrients accumulate in recirculating systems with low water exchange and high feeding rates to levels which approximate hydroponic nutrient solutions (Nair et al., 1985).

Vegetable hydroponics is incorporated into recirculating systems to recover nutrients that would otherwise accumulate or be discharged into the environment. Vegetables are a valuable by-product of fish production that enhance system profit potential. Although nutrients are not a major expense in commercial hydroponics, most essential plant nutrients derived from feed accumulate in recirculating systems at no additional expense, and in a broader sense the use of these nutrients saves the energy that would have gone into making inorganic fertilizers.

Integrating fish culture and vegetable hydroponics can offer additional savings through shared infrastructure (e.g., pumps, reservoirs, monitoring and control systems) and shared overhead (e.g, security systems, administrative support). Nutrient removal by plants improves effluent quality and enhances fish production. Plant roots and hydroponic structures improve water quality by capturing solids and providing surface area for biofiltration (the oxidation of fish waste products by bacteria).

Aquaponic systems use water more efficiently through the interaction of fish and plants (Rakocy, 1989). Water exchange rates can be minimized because plants extract nutrients that inhibit fish growth. Applications of fish feed forestall the need to discharge and replace depleted nutrient solutions. Minimizing water exchange reduces operating costs of aquaponic systems in arid climates.

Aquaponic systems are capital intensive and require moderate amounts of electrical energy from an uninterrupted source. Backup electrical generation is essential.

SYSTEM DESIGN

Although there is wide variability in the design of aquaponic systems, the optimum arrangement of system components consists of a fish rearing tank, as solids removal unit, a biofilter, a vegetable production unit, and a reservoir (Rakocy and Hargreaves, 1993). Biofilter and hydroponic components may be combined if the hydroponic tank and its plant support media provide sufficient surface area for biofiltration.

Figure 1 illustrates an experimental, aquaponic system at UVI in which biofiltration and hydroponic vegetable production are combined. This system consists of a 12.3-m^3 fish rearing tank, a 1.9-m^3 clarifier for solids removal, two 2.1-m^3 hydroponic tanks (6.10 m L x 1.22 m W x 0.28 m D) and a 1.4-m^3 reservoir (sump). Floating polystyrene sheets contain 12.8 m^2 of plant growing area. Total water volume during operation is 17.3 m^3.

Based on this design, a commercial-scale system was developed that contained a larger reservoir (6.8 m^3) for rainwater storage and larger hydroponic tanks (29.59 m L x 1.27 m W x 0.41 m D) with a total growing area of 71.4 m^2 and minimum water volume of 37.1 m^3. Construction of an even larger system is in the planning stages. The experimental and commercial systems are located outdoors and are not covered, with the exception of the rearing tank, which is shaded from sunlight with an opaque canopy.

Most aquaponic system components are constructed from fiberglass, which is sturdy, durable, non-toxic, movable, and easy to plumb. The hydroponic tanks are constructed from cement blocks lined with a high-density polyethylene liner. Poured concrete walls with a polyethylene liner provide a suitable, but more expensive alternative.

COMPONENT RATIOS

Aquaponic systems are designed to meet size requirements for solids removal and biofiltration at the desired level of fish production. The solids removal unit and biofilter are built to a size that provides adequate waste treatment at the maximum fish density and feeding rate. The commercial-scale system at UVI has sustained 400 kg of tilapia and a daily feeding ration of 8 kg.

Another important ratio is the size of the hydroponic component in relation to fish production capacity. The critical determinant in sizing the hydroponic component is the daily feed (nutrient) input to the system. The optimum ratio between lettuce and tilapia was determined by evaluating six plant-to-fish ratios ranging from 1.2 to 7.5 (Rakocy, 1989). Maximum lettuce production (3.1 kg/m^2/crop) occurred at the ratio of 1.9 plants to 1 fish, which was equivalent to a daily feeding rate of 2.4 g/plant. This ratio was used as a guide in designing

UVI's commercial-scale system for lettuce production. A daily feeding ration of 4 to 6 kg is maintained for the staggered production of 2,112 heads of bibb lettuce (density = 29.6 heads/ m^2) or a smaller number of loose leaf and romaine lettuce. The plant growing area is seven times larger than the fish rearing area.

HYDROPONIC SUBSYSTEM

Aquaponic systems employ a wide range of hydroponic subsystems (sand, gravel, nutrient film technique, rafts), but fine media such as sand and gravel is subject to clogging by suspended solids not previously removed from the water flow and by the growth of microorganisms within the media. UVI's commercial-scale system uses a floating (raft) hydroponic subsystem that consists of two long aerated channels, each of which contains 12 polystyrene sheets (2.43 m L x 1.22 m W x 3.8 cm thick). Circular holes (5 cm) are cut through the polystyrene sheets at the desired plant spacing. Transplants are placed into plastic net pots which have been inserted into the holes. Some male tilapia fingerlings are placed into the channels and restricted to the bottom section by a rigid screen to prevent access to the plant roots, which they would consume. The swimming action of the fish prevents the accumulation of solids on the tank floor.

PLANT GROWTH REQUIREMENTS

Maximum plant growth in aquaponic systems requires proper nutrition consisting of six macronutrients (N,P,K,Ca,Mg, and S) and seven micronutrients (Cl,Fe,Mn,Zn,Cu,Mo, and B). A high dissolved oxygen concentration (>5mg/liter) in the water surrounding the plant roots is required for healthy growth. Excessive solids or stagnant water in the root zone leading to oxygen depletion will cause root dieback and water stress within the plant which leads to wilting and blossom-end rot of fruit in crops such as tomatoes. Effective solids removal and aeration of the root zone are major design and operational considerations of the hydroponic subsystem.

Other important factors for hydroponic vegetable production are climatic. Production is generally best with maximum intensity and duration of sunlight. Maintaining an optimum temperature range for hydroponic vegetables may require siting aquaponic systems at higher, cooler elevations in the tropics. Outdoor aquaponic systems require protection from strong winds, especially following transplanting when seedlings are most vulnerable to damage.

WATER QUALITY MANAGEMENT

Dissolved oxygen concentrations of >5 mg/L are required in the fish rearing tank for maximum growth. Numerous aeration systems are available. The UVI system uses a combination of diffused aeration from air stones around the perimeter of the tank and a vertical-lift pump in the center of the tank which sprays water onto the air. A blower provides air to the air stones in the rearing tank and the hydroponic tanks.

Ammonia and feces, the major waste products from fish, require removal from the culture water. Fish excrete waste nitrogen from their gills in the form of ammonia. Dissolved inorganic nutrients are produced by direct excretion from the fish and mineralization of organic matter.

After water is discharged from the rearing tank, feces and suspended solids are removed by a cylindro-conical clarifier with a 60 degree bottom slope, which provides good removal of settleable suspended solids if it is stocked with 20 to 30 male tilapia fingerlings. These fish dislodge solids that adhere to the slope and concentrate them at the base of the cone. Sludge is removed several times daily by opening a drain valve. The clarifier has not been effective at removing fine, colloidal material. A second solids removal unit is being designed to capture fine solids with a filtration mechanism.

Effective removal of solids is necessary for optimum system performance. As solids decompose,

they exert a high biochemical oxygen demand (BOD), which lowers system oxygen levels or requires additional aeration. Microbial decay of organic matter interferes with biofiltration and produces ammonia. Some promising new technologies for removal of solids include bead filters (Malone and Coffin, 1991) and various screen filters (Tetzlaff, 1991).

Additional treatment of sludge and nutrient-enriched effluent is required prior to discharge to mitigate environmental impact. Options for stabilization of sludge and effluent include aerated and anaerobic lagoons, aerobic and anaerobic digestion, and composting (Chen et al., 1991). Effluent may be applied to land as irrigation water. Stabilized sludge can also be disposed of by land application as a soil amendment.

Following the clarifier, culture water passes to a biofilter designed primarily for the oxidation of ammonia and nitrite through the growth of nitrifying bacteria. Ammonia is oxidized to nitrite by Nitrosomonas bacteria and nitrite is oxidized to nitrate by Nitrobacter bacteria. Ammonia gas and nitrite are toxic to fish at low concentrations (<1 mg/L) while fish tolerate very high nitrate levels (>100 mg/L). Nitrifying bacteria occur naturally in water and require one month to colonize biofilter surfaces. The feeding rate is reduced during the biofilter acclimation period.

Aquaponic-system biofilters employ sand, gravel, shells, or various plastic media as substrate for microbial attachment. One of the leading biofilter designs is the rotating biological contactor (RBC), which consists of many fiberglass disks mounted on an floating axis. Continuous rotation of the axis alternately exposes the disks to culture water and air, creating an ideal growing environment for nitrifying bacteria.

The UVI system initially contained two 93-m^2 RBCs located after the clarifier. Each hydroponic tank provides 126 m^2 of additional surface area. Midway through a production trial, the RBCs were removed to determine if the hydroponic tanks could provide adequate nitrification at the design feeding rate of 4 to 6 kg/day. Low ammonia and nitrite levels were maintained, thereby demonstrating that raft hydroponics eliminates the need for a separate biofiltration unit at the optimum plant-to-fish ratio.

Hydroponic vegetables contribute to water quality improvement by direct uptake of dissolved nutrients, including ammonium ions. Loose leaf and romaine lettuce are estimated to remove about 32% of total dissolved nitrogen from UVI's commercial-scale system.

The oxidation of ammonia and nitrite is a process that produces acid, thereby lowering pH. If pH values decrease to less than 7.0, nitrification becomes less efficient and ammonia and nitrite levels rise. It is necessary to monitor pH on a daily basis and to add small amounts of base to maintain pH values near 7.0. However, too much base will reduce the availability of many micronutrients to plants.

Common bases for aquaponic systems include calcite ($CaCO_3$), dolomite ($CaMg(CO_3)_2$), caustic potash (KOH), quick lime (CaO), and hydrated lime ($Ca(OH)_2$). Baking soda ($NaHCO_3$) is not a suitable base because Na^+ can accumulate to levels that are toxic to plants. Caustic potash and quick lime are used at UVI.

NUTRIENT ACCUMULATION

Nutrients accumulate in recirculating systems as a consequence of low water exchange and high feeding rates. Nutrient accumulation is one of the critical design and management considerations of aquaponic systems. The accumulation rate is a function of feeding rate, food composition, nutrient supplementation, solids removal efficiency, plant uptake (number and growth stage), and water exchange rate. Once the desired nutrient concentration is obtained in the culture water, some of these variables (e.g., water exchange rate) may be manipulated in an effort to maintain steady-state conditions.

Nutrient accumulation increases the conductivity of culture water. In an aquaponic system with a low rate of water exchange (<1% system volume/day), conductivity increases at approximately 200 g as TDS (total dissolved solids)/kg of dry weight of feed applied (Rakocy et al., 1993). Critical

conductivity is obtained at approximately 2000 mg/L as TDS (3125 micromhos/cm), or after the addition of 10 to 20 kg of feed/m^3 of system volume depending on the quantity of plant growth. Higher conductivity can be detrimental to plant growth. The relative accumulation of different nutrients approximately reflects feed composition for macronutrients (N>Ca>K>P>Mg) and micronutrients (Fe>Zn>Mn>B>Cu).

The ability to control the nutrient composition of fish culture water is limited. Nutrients in fish culture water do not reach levels (2000 mg/L as TDS) normally utilized in commercial vegetable hydroponics without the addition of large amounts of feed. However, aquaponic-system water is suitable for plant culture after the addition of relatively small amounts of feed and at TDS levels <500 mg/L. When an aquaponic system is put into operation, the fish are added a few weeks before the first planting to allow time for nutrients to accumulate to the minimal levels required for good plant growth.

The water source for UVI's aquaponic systems is rainwater, which is collected on catchments and stored in large, covered tanks. The low TDS levels (<100 mg/L) of rainwater extend water usage. The ground water of semiarid islands such as St. Croix generally has high TDS levels and large amounts of sodium ions. The surface water and groundwater of wet, mountainous, Caribbean islands have lower TDS levels and may be suitable for aquaponic systems.

NUTRIENT SUPPLEMENTATION

Although nutrient salts accumulate in aquaponic systems, not all of the essential nutrients are present in sufficient quantities. Nutrients that require supplementation in the UVI system are potassium (as KOH), calcium (as CaO or $Ca(OH)_2$), and iron (as iron chelate containing 10% iron by weight). Approximately equal weights of KOH and CaO are alternately added to the sump to maintain pH at 7.0. Frequent, small additions prevent wide swings in pH which are harmful to both fish and plants. Iron is supplemented every 3 weeks by adding 2/mg/L. Iron may be applied as a dilute foliar spray (0.1% Fe-EDTA) in combination with a surfactant. Nutrient deficiencies may vary depending on the water source (chemistry), fish feed and hydroponic substrate used.

SUITABLE SPECIES

Several species of fish have been cultured in aquaponic systems, but the most appropriate species for the Caribbean is tilapia, a hardy, freshwater species that is native to Africa and the Middle East. Tilapia tolerates crowded conditions and handling. It is resistant to diseases, grows quickly, converts feed efficiently, and tastes delicious. Red tilapia hybrids resemble colorful ocean fish and are readily accepted by West Indians. Florida red tilapia and Nile tilapia (Oreochromis niloticus) are being cultured at UVI.

A wide range of vegetables have been grown in aquaponic systems, including high-value cash crops such as tomatoes, lettuce, and cucumbers. Lettuce is particularly suitable for aquaponic-system culture. A crop of lettuce can be produced in a short time period from transplanting, and, as a consequence, pest pressure in relatively low. Lettuce has been the main crop used in the development of aquaponic systems at UVI. Other crops with potential include pak choi, Chinese cabbage, peppers, herbs such as sweet basil and chives, bush beans, and celery.

FISH STOCK MANAGEMENT

A continuous mode of fish rearing is required in aquaponic systems for maximal utilization of production capacity. Aquaponic systems are less efficient if they are operated in a batch mode, whereby a fixed number of fingerlings are stocked and raised to marketable size over several months as the daily feeding ration is gradually increased up to the maximum allowable feeding rate for maintenance of acceptable water quality. With continuous rearing, the system is operated at a level

of fish biomass and daily feed application that is near the carrying capacity at all times. Operation of the system near the carrying capacity will assure a constant supply of dissolved nutrients for hydroponic plant production.

The UVI system has been operated in a continuous production mode by using a stock splitting method (Van Gorder, 1991). The rearing tank is stocked with a large number (1,000) of fingerlings so that the initial feeding rate will permit maximum plant growth. As the fish grow and require more feed, a portion (250) of the stock is removed every 6 weeks. In a commercial operation, these fish would be placed in other production units that are also operated near the carrying capacity. With stock splitting, the feeding rate remains relatively constant throughout the entire 24-week production cycle. The fish are allowed unrestricted access to feed from demand feeders. Using a complete diet (floating pellets, 32% protein), UVI's commercial- scale system is capable of producing 1280 kg of tilapia annually.

Stock splitting is stressful to fish and requires considerable labor. In large operations, the logistics of moving fish is difficult. A system of multiple rearing units, all of which are connected to one hydroponic subsystem, may be more efficient. Each rearing tank would contain a different size group of fish to allow continuous production. Although feeding rations to the individual rearing units would vary according to fish biomass, the overall feeding rate to the system would be relatively constant. This method will be tested in a new, commercial-scale system that is being built at UVI.

Fish grown in intensive production systems are subject to acquiring off-flavors in their flesh by absorbing odorous compounds through their gills. The compounds are produced by natural biological processes in the culture system. Tilapia are always tested for flavor before they are sold and routinely placed in clean water for a week to purge any off-flavors that are detected.

CROP PRODUCTION SYSTEMS

A staggered crop production system is one in which plant groups in different stages of growth are cultivated simultaneously in the hydroponic subsystem. This production system allows regular harvest of produce and relatively constant nutrient uptake from culture water. Leafy green vegetables, herbs and other crops with short production cycles are well-suited for continuous production systems. The UVI system uses a 3 or 4-week staggered production schedule for leaf lettuce. From 12 to 29 cases of lettuce (288 to 704 plants) are harvested every week depending on lettuce type. The harvest takes place in the morning and is immediately followed by transplanting with 3-week-old, greenhouse plants. Planting density varies from 16.2 to 29.6 plants/m^2.

A batch cropping system is more appropriate for vegetables with extended growing periods such as tomatoes and cucumbers. Various intercropping systems are also used. Lettuce is often intercropped with tomatoes or cucumbers. One crop of lettuce is harvested before the tomato or cucumber canopy develops.

PEST AND DISEASE CONTROL

A number a plant pests have been encountered in UVI's aquaponic systems. Pests observed on tomatoes include spider mite, russet mite, hornworm, fall army worm, pinworm, aphid, and leaf minor. Lettuce has been affected by fall army worm and cabbage looper. Pak choi and Chinese cabbage have been attacked by aphids. Most pesticides cannot be used in aquaponic systems to control insect outbreaks on vegetables because of their toxicity to fish or because they have not been approved for use in fish culture. Similarly, most therapeutants for treating fish parasites and diseases should not be used either. Vegetables may absorb and concentrate them. Even the common practice of adding salt to treat fish diseases or reduce nitrite toxicity would be deadly to vegetables.

Insect control techniques for vegetables in aquaponic systems are limited to the use of biological control, traps, resistant varieties, screening, and specialized cultural practices. For example, screening

or weekly spraying with Bacillus thuringensis (Thuracide), a biological control agent, are very effective in the control of fall army worms and cabbage loopers on lettuce.

Limitation on the use of pesticides is a disadvantage to crop production in aquaponic systems. However, this restriction assures that crops from aquaponic systems will be raised in an environmentally-sound manner and will be free from pesticide residues. A major advantage of the UVI system is that crops are less susceptible to attack from soil-borne diseases. It also appears that aquaponic systems may be more resistant to diseases that affect standard hydroponics. This resistance may be due to the presence of some organic matter in the culture water which creates a stable, ecologically-balanced, growing environment with a wide diversity of microorganisms.

VEGETABLE YIELDS

Crop yields from UVI's aquaponic systems have been greater than yields from local field crops and comparable to average yields of soilless culture. The tomato varieties Sunny and Floradade yielded 10.1 and 9.0 kg/plant (18.4 and 16.3 kg/m^2) of ripe fruit over a 16-week production period. Chinese cabbage (50-Day Hybrid) and pak choi (Le Choi) attained average weights of 638 g (11.3 kg/m^2/crop) and 508 g (8.7 kg/m^2/crop) over a 4-week production cycle from transplant stage. Lettuce yields of 786 g/plant (12.7 kg/m^2) have been attained for Montello (a crisphead variety) in a 5-week growing period, 660 g/plant (10.7 kg/m^2) for Parris Island (a romaine) in 4 weeks, and 522 g/plant (8.4 kg/m^2) for Sierra (a red loose leaf variety) in 4 weeks.

OUTLOOK AND POTENTIAL

A partial economic analysis of UVI's commercial-scale system indicates that the system has profit potential in St. Croix (Bailey et al., 1994). This study concentrated on capital costs, operating costs and revenue of one production unit but did not consider overall infrastructural or administrative costs for a full-scale operation. A comprehensive economic evaluation will be undertaken after the present commercial system is scaled up in size by a factor of three. This evaluation will determine economies of scale, based on number of production units, and develop enterprise budgets. However, results of economic studies in St. Croix will have limited application to other Caribbean locations. Each operation will require a site-specific analysis of cost, revenue and potential profits.

A marketing study of aquaponic-system products has been conducted for more than a year with very encouraging results. Lettuce has been sold to 42 outlets in St. Croix, ranging from wholesalers to tourist restaurants, while tilapia has been sold to 21 outlets, primarily West Indian restaurants. The most attractive features of these products have been their freshness and high quality. The continuous production schedules of commercial aquaponic systems would meet another strong consumer demand: consistency of supply. Local production from aquaponic systems offers an attractive alternative to expensive food imports that are often poor in quality.

Attempts to increase fish and vegetable supplies in the Caribbean have been hindered by insufficient knowledge of appropriate production techniques or resource limitations. These barriers may be overcome through the intensive production of fish and vegetables under controlled conditions in aquaponic systems, which conserve land, water and nutrients. Although more complex than traditional production methods, aquaponic systems are reliable and easy to operate after the basic principles are learned. Being on the threshold of commercial development, aquaponic system technology holds promise for the future of Caribbean agriculture.

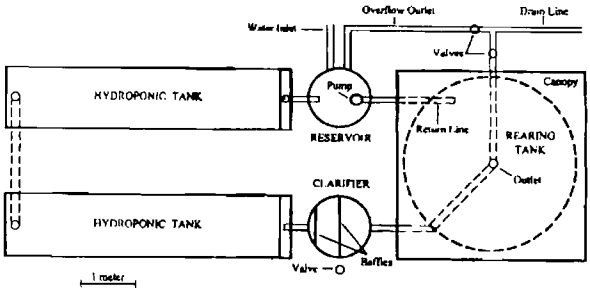

Figure 1. A closed recirculating system for integrating vegetable hydroponics with fish culture.

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THE USE OF WITHAM COLLECTORS TO INCREASE PRODUCTION IN LOBSTER (*PANULIRUS ARGUS*) MARICULTURE

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ABSTRACT

The western Atlantic spiny lobster (*Panulirus argus*) is the largest and the most widely distributed Caribbean lobster. Because of the high consumer demand and high price consumer's are willing to pay for lobster, scientists are exploring ways to raise lobsters in captivity. One approach to producing lobsters is full scale mariculture where lobsters are raised throughout their entire life cycle in captivity. Although researchers have successfully mated and spawned spiny lobsters in captivity, they have found it difficult to rear the larvae because of their long and complex larval life. Another approach is to collect the first lobster settlement stage, the puerulus, from the wild. The transparent pueruli settle in shallow water natural habitats such as mangroves and on artificial habitats, called Witham collectors. In the U.S. Virgin Islands pueruli settlement occurs all year round with seasonal settlement peaks. The collection of pueruli is a cheaper, easier, and faster technique to establish a lobster mariculture operation than developing and maintaining a breeding stock and raising larvae to settlement stage. Interest in lobster mariculture is likely to continue to increase as the human population increases and as diet-conscious people increase their sea food consumption. Maximum sustainable yields for lobster fishing in many islands have already been exceeded and more effort is being spent on techniques to make lobster mariculture profitable.

INTRODUCTION

The world's population consumed 62% of the estimated maximum sustainable yield for finfish in 1978. United Nations fisheries scientists estimated that by 1985 the world demand for finfish would exceed the maximum world supply in all major fisheries (Van Olst, 1980). It is now 1994 and major fisheries on the northeast coast of the USA have declined precipitously and drastic action--the complete closing of a major fishery and at least the temporary loss of thousands of jobs--has occurred. This is not the first fishery that has collapsed, nor will it be the last.

The western Atlantic spiny lobster, *Panulirus argus*, supports a small commercial/recreational fishery in the U.S. Virgin Islands. USVI catches from 1980-1988 were fairly stable at 19 tons (NOAA, 1992), but appear to have declined since the 1960s (Swingle, *et al.*, 1969). Despite the recent total catch stability, inshore stocks of lobsters have been depleted and fishermen must travel further offshore, spending more time and exerting more effort to catch lobster. Of course, the high price of lobster still makes lobster fishing profitable. Whole lobster sells from about $5-6.00 per lb locally. Frozen tails cost up to $21.00 per lb.

The high price of lobster and high consumer demand make the spiny lobster a potential candidate for mariculture. Spiny lobsters also have other characteristics that make them amenable to commercial cultivation. These include their communal nature, lack of aggressive or cannibalistic behavior, and the wide variety of food that they will accept (Ingle, 1979). *Panulirus argus* also has a fast growth rate if maintained at temperatures between 27 and 30°C. Lellis (1991) grew *P. argus* to market size in 16 months.

Although researchers have successfully mated and spawned spiny lobsters in captivity, they have

found it difficult to rear the larvae, perhaps because of their long and complex larval development. The oceanic phyllosoma larvae of *Panulirus argus* metamorphose after an estimated at 6-9 months (Ingle *et al.*, 1963) into transparent nocturnally active pueruli which swim to inshore nursery areas aided by physical transport mechanisms (Lyons, 1980; Calinski and Lyons, 1983). There are 11 phyllosome larval stages, followed by a puerulus stage (Lewis, 1951). The pueruli settle selectively among structurally complex benthic vegetation, particularly the common benthic algae, *Laurencia* spp. (Marx and Herrnkind, 1985; Herrnkind and Butler, 1986; Marx, 1986; Butler and Herrnkind, 1991), among mangrove roots, on dock pilings, and boat bottoms. Settled pueruli metamorphose into first benthic instars (Sweat, 1968) 5-7 mm in carapace length. Unfortunately, the complex biological requirements of culturing phyllosome lobsters make this task more difficult than the domestication and rearing of terrestrial animals such as poultry and livestock.

Pueruli are often seen in large numbers in shallow water habitats and it has been suggested that it may be possible, if recruitment of pueruli is in excess of natural population requirements, to capture sufficient numbers of puerulus stage lobsters for aquaculture. Collecting pueruli in the wild as they drift inshore would eliminate the need to establish costly larval rearing facilities. This approach was first suggested over 25 years ago (Ingle and Witham, 1968; Chittleborough, 1974; Serfling and Ford, 1975). The transparent pueruli settle readily on artificial habitats, called Witham collectors. These collectors have been found to be a good relative measure of the number of pueruli in an area (Witham *et al.*, 1968) and have been used to make general comparisons of puerulus abundance among regions (Little and Milano, 1980).

This study focussed on the spatial and temporal variability of pueruli settlement and examined the potential for using pueruli in lobster mariculture. We asked the following questions:

1. Does the recruitment rate of pueruli vary with habitat?
2. Are there seasonal settlement patterns?
3. Is there variation in settlement associated with lunar phase?
4. Does settlement vary between years?
5. Is there regional variation in the settlement rate in the Caribbean?

MATERIALS AND METHODS

Biological Sampling

Lobster pueruli were collected using modified Witham collectors. The collectors consist of six pieces of plastic coated "hogshair" air conditioning filters each 45cm x 55cm, for a total of 1.5m^2 of surface area. The filters are supported by a PVC frame. The capital cost for a single collector is about $40. This could be reduced if used air conditioning filters were used. The filters need to be replaced when they began to disintegrate. The replacement frequency in this study was between 3 - 6 months after immersion. Settlement on replacementcollectors was comparable with the settlement on collectors that had been deployed for several months.

Three sites on the south side of St. Thomas were chosen for study: the Mangrove Lagoon, Saba Island and Great St. James Island (Fig. 1a). In June 1992, three modified Witham collectors were placed in Mangrove Lagoon (Fig. 1b). The collectors were deployed at a depth of 1 m in water 2 m deep over a substrate of fine sand and mud. The mangrove community was dominated by the red mangrove, *Rhizophora mangal* (Nichols and Towle, 1977). In July 1992, two additional collectors were deployed in waters off Saba Island 3 km offshore of the southwest end of St. Thomas. The collectors were moored 3 m from the surface in water 8 m deep. They were positioned between a manatee/turtle grass (*Syringodium filiforme/Thalassia testudinum*) sea grass meadow and a *Montastraea annularis/Millepora* sp. dominated reef. A further two collectors were deployed off Great St. James on the southeast end of St. Thomas at a similar depth with similar features.

The Witham collectors were sampled approximately fortnightly by placing a 2 mm mesh bag around each collector and inspecting each collector on board a 21 foot open boat. All pueruli were removed from collectors, counted, and staged, and then collectors were returned to the water. Each sample represented recruitment to the collector over a 10 to 15 day period. When considering lunar effects, the phase before or on the sampling date was used.

The measure of catch per unit effort (CPUE) was determined by dividing the number of pueruli counted by the number of collectors at the site and further standardizing for the number of days between collections.

Hydrological Sampling

Subsurface sea water temperature was recorded hourly to the nearest 0.05°C at the location of one of the collectors off Saba Island from 28 March 1992 to 30 March 1994 using a Hugrun Seamon s/f brand underwater temperature recorder (UTR).

RESULTS

In 16 months of sampling, 36 transparent, 53 semi-pigmented and 331 pigmented post larvae, totaling 420 pueruli or post-larval lobsters (Fig. 2), were collected in a total of 227 samples (one sample refers to one Witham collector sampled at a single sampling time). Settlement of at least one individual was observed in 77% of the samples.

Three treatments (lunar phase, site, and month) were considered in an Analysis of Variance test of catch data (Table 1). Catches were very highly significantly affected by site location, month, and interaction of site and lunar phase. Lunar phase was not a significant influence when all the sites were pooled.

Seasonal Variation

Although settlement occurred throughout the year, the settlement rate from April to October, the summer months, was 2.8 times greater than from November to March, the winter months (Fig. 3).

Lunar Variation

It has been suggested that pueruli settle primarily during the new moon phase. However, only at Saba Island was settlement statistically significant with respect to lunar phase (t-test, $N=16$, $P<0.022$). At this site, settlement around new moon was over six times greater than during full moon. During new moon phase, catches at Saba Island ranged from 0 to 6.5 CPUE per collector while during the full moon phase catches ranged from 0 to 2.0 CPUE (Table 2). Only once were catches greater during a full moon period than during either of the juxtaposed new moon collections.

Settlement was greater at new moon at Great St. James and the Mangrove Lagoon (Table 2), but the results were not statistically significant.

Annual Variation

There has been an overall decline in CPUE between years in the Great St James and Saba sites (Fig. 4). Settlement in 1993 at Great St. James and Saba was only 14% and 11% of 1992 settlement, respectively. However, settlement within the Mangrove Lagoon estuary was 41% greater in 1993 than in 1992. These inter-annual variations probably reflect the natural variability of lobster settlement which is influenced by currents and tidal flow, among other factors.

Spatial Variation

Large significant differences in the number of post larvae settling existed between sites (Fig. 5). Settlement was highest on the two collectors at the entrance to the Mangrove Lagoon with a CPUE (catch per unit effort) of 6.04 pueruli. Pueruli were present on 72% of the sampled dates at that site. The next highest settlement rate was on collectors located at Great St. James Island. This site had a CPUE of 2.29 puerulus and puerulus were caught in 70% of the samples. The off-shore island, Saba, had a CPUE of 1.03 and pueruli were present on 45% of the sampling dates. The collector located furthest inside the Mangrove Lagoon estuary had the lowest settlement rate (0.55 CPUE) with pueruli settling on only 38% of samples. Witham collectors are considered less effective within estuaries since they must compete with natural habitat suitable for pueruli settlement.

The Great St. James site, with the second highest lobster recruitment, is adjacent to Current Cut which experiences water movement up to 50 cm/sec. Currents along with wind-induced surface water movement probably enhancesettlement at this site. The Saba Island site which is furthest away from an estuary receives a near constant easterly current, but experienced the least settlement with a settlement rate of only 17% of the settlement rate in the estuary.

Sea water temperature

The sea water temperature range was 4.45°C. The highest temperature recorded was 29.6°C in October 1992 and lowest 25.15°C in January 1993 (Fig. 6) (Quinn and Kojis, 1994). The CPUE was not significantly correlated with water temperature ($r = 0.26$, $N = 16$).

DISCUSSION

The potential for commercial success of a lobster mariculture project is enhanced by collecting the greatest number of puerulus with the least effort. Consequently, knowledge of the optimal location and time for collection is essential.

Temporal Variation

Pueruli settlement was seasonally variable with the greatest settlement occurring in the 6 months from April to October. However, during the summer months fewer pueruli settled when the wind speed decreased to less than 5 knots for over two weeks.

It has been suggested that recruitment rates may be related to temperature. In Bermuda, Ward (1989) reported that most settlement occurred in late summer with virtually no mid-winter recruitment. Ward suggested that the cooler oceanic water around Bermuda (32°N) in winter may act to inhibit the metamorphosis of the phyllosoma to the puerulus stage and suggested that 24°C might be the lower limit.

In St. Thomas, water temperatures do not fall below 25.1°C and average monthly temperatures are between 26 and 29°C (Fig. 6). Although some settlement occurred throughout the year, the period of lowest recruitment from November to March coincided with the period of lowest temperatures and this tends to support Ward's hypothesis. However, settlement of pueruli occurs mainly from February to May in Florida which spans winter and spring months and suggests that low temperatures do not necessarily inhibit larval metamorphosis.

Time of spawning may also be a factor influencing pueruli availability. Year round spawning of *Panulirus argus* was recorded for the neighboring island of Puerto Rico (Mattox, 1956). However, no data were available on the annual variation in spawning intensity in Puerto Rico.

With any renewable natural resource the knowledge of various parameters such as mortality, fecundity, recruitment, and habitat preference can be used topredict population sizes and thereby regulate harvest and protect nurseries. However, studies of recruitment of *Panuluris argus* are difficult

owing to the long (6-9 month) pelagic larval stage. The specific sources of the phyllosoma larvae and pueruli to Virgin Islands stocks, each source's contribution to the stocks, an accurate determination of the length of time the larvae spend in the plankton, the growth rates of the larvae, and the conditions relating to their movement to inshore waters are still unknown.

Spatial Variation

Although collectors at the entrance to the Mangrove Lagoon estuary had the highest CPUE, the estuary is not a pristine habitat. Over one half million gallons per day of minimally treated effluent from four sewage treatment plants are discharged directly into the mangrove lagoon or its water shed. The effluent is discharged down current from the collectors throughout most of the year. However, when the trade winds die and the wave induced flushing ceases, especially for extended periods as occurs commonly in September and October (Mortenson, n.d.), the lagoon water becomes green and visibility decreases to less than 0.3 m. The Witham collector furthest in the estuary had the lowest CPUE. However, Witham collectors are considered less effective within estuaries because they compete with natural settlement areas. Further study is necessary to determine if the poorer water quality inside the estuary contributed to the lower settlement rate on this collector.

The Great St. James site, with the second highest level of lobster recruitment, is adjacent to Current Cut which experiences water movement up to 0.5 m/sec^{-1} compared with 0.1-0.2 m/sec^{-1} at other sites. Currents along with wind-induced surface water movement probably enhance settlement. The site furthest away from an estuary at in the leeward side of Saba Island receives a nearly constant easterly current, but experienced the least settlement with settlement rates 17% of those in the estuary.

Regional Variation

Settlement is variable not only within an island group, but between island groups. For example, in Antigua, the highest settlement rate was on the five collectors in locations that receive direct exposure to the southeast trade winds and eastwardly flowing equatorial current (Anon., n.d.). However, not all sites on that side were highly productive. It is unclear what effect currents, eddies or other types of micro-environment have in concentrating pueruli.

In southern Florida collectors deployed in channels had less settlement than collectors in slower moving water juxtaposed to channels (Little, 1977). In Bermuda, the greatest settlement occurred on collectors adjacent to major channels that pass a large volume of water. Ward (1989) observed that some water movement will increase settlement, but there may be a flow rate, which when exceeded, results in reduced settlement.

The high CPUE in the outer Mangrove Lagoon collectors in St. Thomas compares favorably with the observation by Little (1977) in Florida that postlarvae were more abundant in collectors placed in mangroves than in collectors placed in deeper channels. Little (1977) interpreted this to suggest the importance of the near-shore environment as juvenile nursery areas and this study supports his contention.

Along with differences in preferred settlement locations between different areas, settlement rates vary between island groups. Simultaneous puerulı settlement rates were obtained from August 1987 through July 1988 in Antigua, Florida Keys, and Bermuda (Hunt, *et al.*, 1990). The mean catch per collector (CPUE) ranged from 9.3 puerulus in Antigua, 6.1 in Florida Keys and 1.4 in Bermuda (Table 3). The CPUE for the Mangrove Lagoon, 6.04 puerulus, was comparable with settlement rates from the Florida Keys, but was 35% lower than that reported in Antigua. The off-shore site at Saba Island had a CPUE 1.03 that was comparable to the CPUE obtained in the off-shore waters around Bermuda (Fig. 7).

Another Antigua study (Anon. n.d.) with 35 collectors lasted 4 1/2 months. Settlement exceeded values obtained in this study in only two months, September and October in Antigua. The settlement

in Antigua was 26% greater than this study in September 1992 (Antigua: 3.5 lobsters per collector (lpc), V.I. 2.8 lpc) and nearly 5 times greater than in October 1992 (Antigua: 6.3 lpc, V.I. 1.3 lpc). Another study in Antigua (Peacock, 1974) found settlement much higher in May and October.

Implications for Mariculture

According to van Olst *et al.* (1980), the essential characteristics that make an organism amenable to commercial aquaculture include:

1) an adequate consumer demand and profit potential for the species,
2) high food conversion efficiency,
3) resistance to disease,
4) the ability to reproduce in captivity, and
5) simple larval development

As mentioned earlier, there is a high consumer demand and consumers pay a high price for lobster. Also studies have shown that high water temperatures decrease grow out time and increase food conversion efficiency considerably. Water temperature in the Virgin Islands hovers around the ideal grow out temperature of 27 to 29°C. Most lobsters have proved to be hardy and the spiny lobster is probably resistant to disease although this needs to be studied. The only characteristic that is not met by this species is simple larval development. The length of larval development makes larval rearing costly and, at this stage, difficult.

The use of Witham collectors in regions with high puerulus abundances could increase the success of mariculture operations by eliminating the necessity to raise larvae. Clearly it would be cheaper and easier to use lobster pueruli from natural populations to establish a lobster mariculture operation than developing and maintaining a breeding stock and raising larvae for 6 to 9months. While this study used small experimental collectors, a commercial operation would probably deploy more and larger collectors.

Our study showed that Witham collectors can be used in the Virgin Islands to collect lobster pueruli and that to minimize time and effort of collection it is important to consider the site where collectors are placed. For example, areas near mangroves have the highest recruitment rates. Sites near reasonably strong currents also have high recruitment. Recruitment is seasonal with the spring and summer months having the highest recruitment rates. Lunar phase did not appear to be important with no statistically significant difference in the lunar time of settlement for the two sites with the highest recruitment rates.

Pueruli collection is, however, still fishing. The very long duration of larval stages presents problems in determining the source of recruits and the probable location of spawning population (Richards and Potthoff, 1981). There are no reliable regional estimates regarding what percentage of the puerulis survive to adults. Consequently, the effects on the natural population of collecting hundreds of pueruli cannot be assessed. It is, however, likely that natural mortality is high and that in a well-run mariculture system mortality is likely to be less.

If commercial mariculture of lobsters is successful, producers will need to convince permitting agencies that capture and removal of pueruli will not affect natural lobster populations. Studies of year-to-year fluctuation in the magnitude of *Panulirus* puerulus recruitment have been done in Florida (Herrnkind and Butler, 1986; Herrnkind *et al.*, 1988; Hunt *et al.*, 1990), Bermuda (Ward, 1989; Farmer, *et al.*, 1989), Antigua (Peacock, 1974), and with another species of *Panulirus* in Hawaii (MacDonald, 1986). Settlement variability implicates puerulus recruitment levels as a possible factor regulating harvestable stock abundance. Therefore, monitoring of the effect of puerulus collection on natural populations is important. The question is how to do this. The contribution of local reproductive stock to recruitment in any given area is unknown, but it is likely that most of the larvae are transported hundreds of kilometers before they settle (Phillips and McWilliam, 1986).

Careful records of puerulus CPUE by mariculture operators will help to determine the effect of puerulus "fishing", especially if lobster mariculture becomes widespread in the Caribbean. It will also be important to ensure accurate reporting of catch and effort in the local lobster fishery.

Additionally, producers would also need to consider releasing a percentage of grow out stock, especially females, to replenish the stocks. As most pueruli in a given area are considered to have originated from up current (Lyons, 1981; Menzies and Kerrigan, 1979) the replacement of pueruli with older lobsters is more likely to aid fisheries down current than local fisheries in the short term. Survival of these farm-raised females in the wild will need to be monitored.

Interest in lobster mariculture is likely to continue to increase as the human population increases and as diet-conscious people increase seafood consumption. Maximum sustainable yields for lobster fishing on many islandshave already been exceeded. Lobster mariculture may be a method of relieving pressure on natural populations while meeting consumer demand.

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Table 1: ANOVA Between Lunar phase, site and month.

SOURCE	DF	SS	MS	F	P
MOON(A)	1	2.17	2.17	0.21	0.6519
MONTH(B)	14	708.55	50.61	4.83	0.0002
SITE (C)	2	291.35	145.67	13.91	0.0001
A*B	2	95.35	47.67	4.55	0.0194
A*C	28	1079.98	38.57	3.68	0.0005
A*B	14	96.15	6.86	0.66	0.7955
A*B*C	28	293.311	10.47		
TOTAL	89	2566.89			
GRAND AVG.	1	1521.11			

Table 2: Lunar cycle variation on catch per unit effort.

	TOTAL #PUERULI	TOTAL #PUERULI	1TRIP MAZ.	1 TRIP MAX.
SITE	FULL MOON	NEW MOON	FULL MOON	NEW MOON
GT ST. JAMES	31	56	17	33
SABA	0	25	0	13
MANGROVE	15	28	8	12

Table 3: Catch per unit effort of puerulus at various latitudes in the Caribbean Sea.

ISLANDS	LATITUDE	NUMBER OF COLLECTORS	MAX. CATCH	PEAK MONTH	MEAN CPUE	SITE
ANTIGUA	17°N	28	355	Feb/May Aug.	9.3	
USVI	18°N	7	29	August	6.04	Mangrove Reef
					2.29	St.James
					1.03	Saba
					9.55	Mangrove Inside
FLORIDA KEYS	25°N	3	61	August	6.1	
BERMUDA	32°N	10	44	March	1.4	

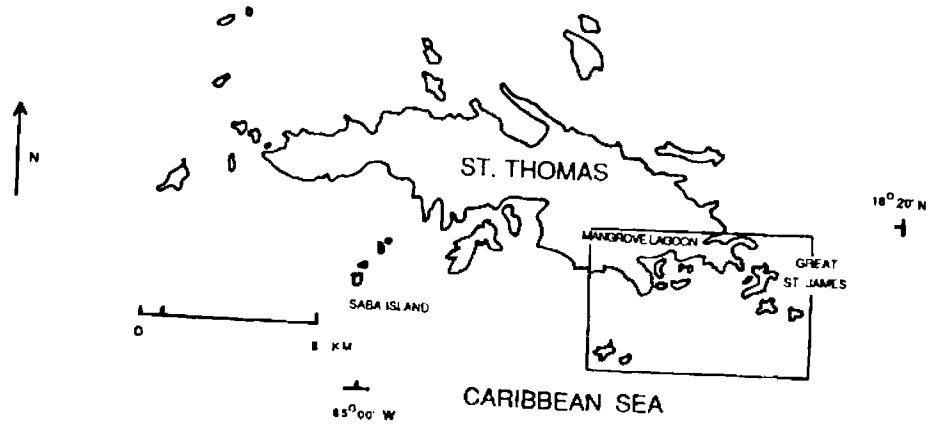

Fig. 1a: St. Thomas, U.S. Virgin Islands.

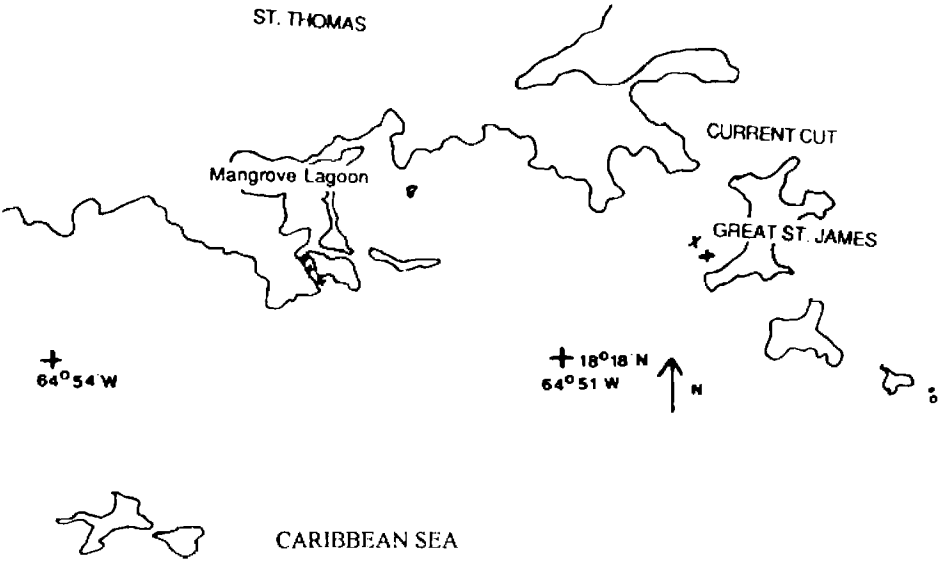

Fig. 1b: Eastern end of St. Thomas. Puerulus collector sites indicated by x.

WITHAM COLLECTOR DATA

LOBSTER PUERULUS

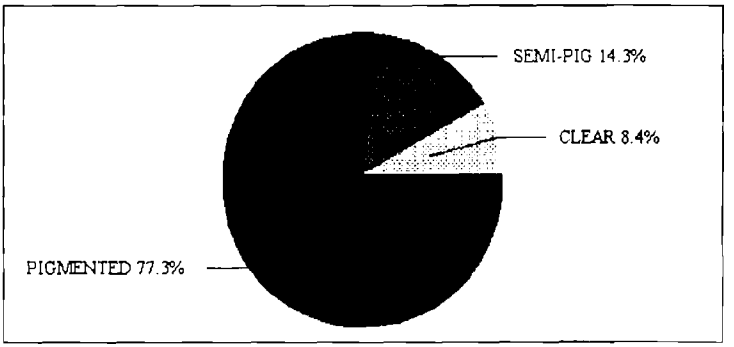

Fig. 2. Percentage of each puerulus stage for all sites.

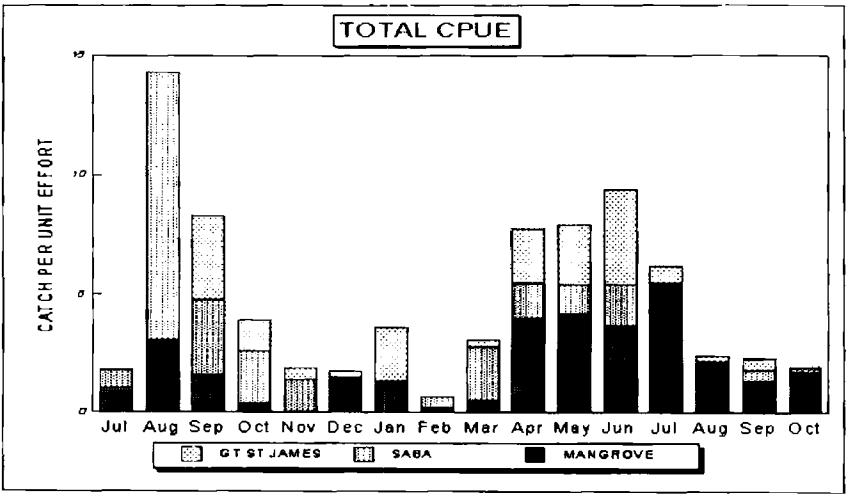

Figure 3. Monthly variation in catch per unit effort (CPUE) by site

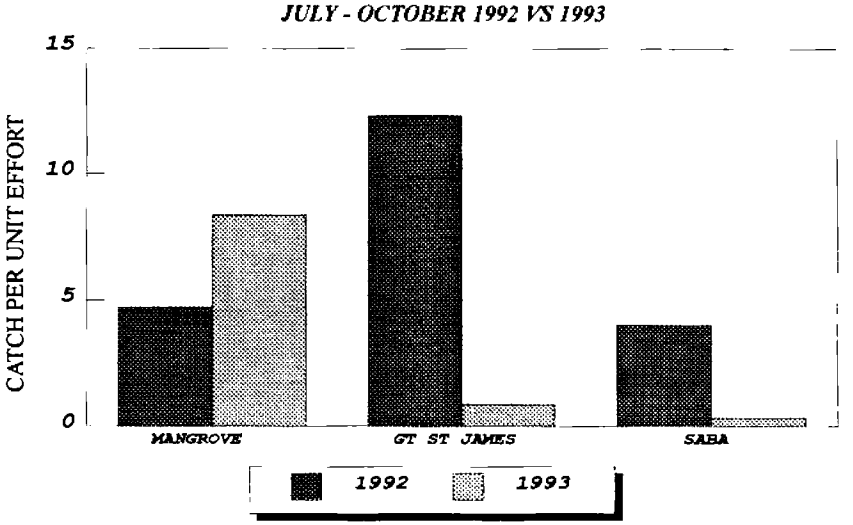

Fig. 4. Variation in catch per unit effort by year.

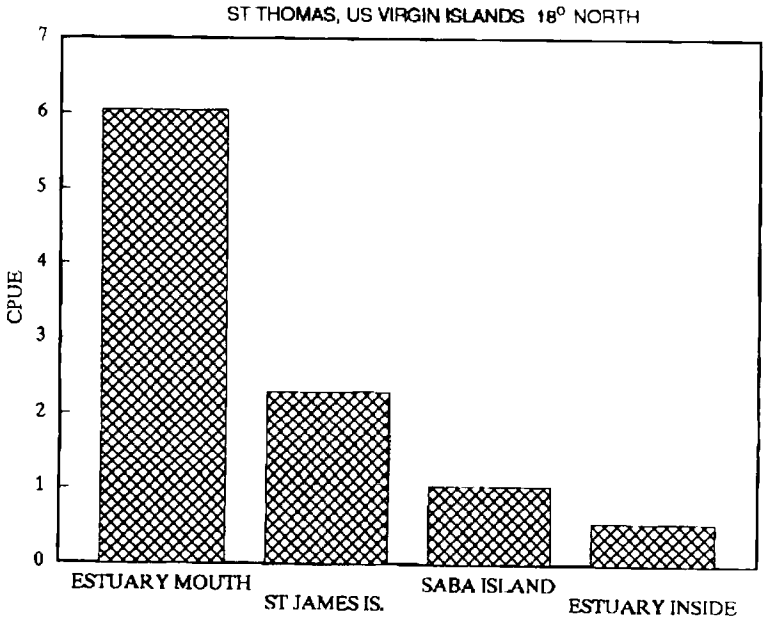

Fig. 5. Variation in catch per unit effort by site.

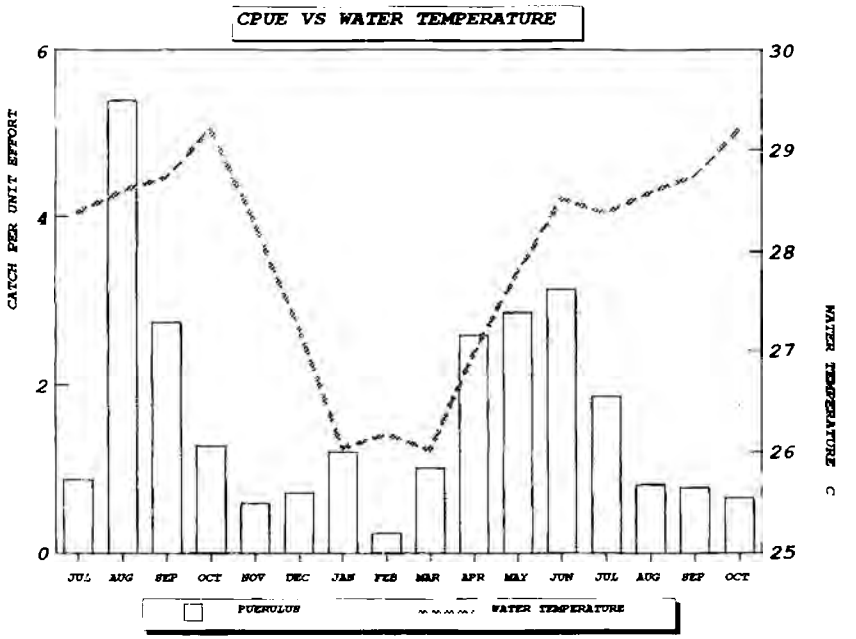

Fig. 6. Monthly total catch per unit effort and mean monthly subsurface sea water temperature.

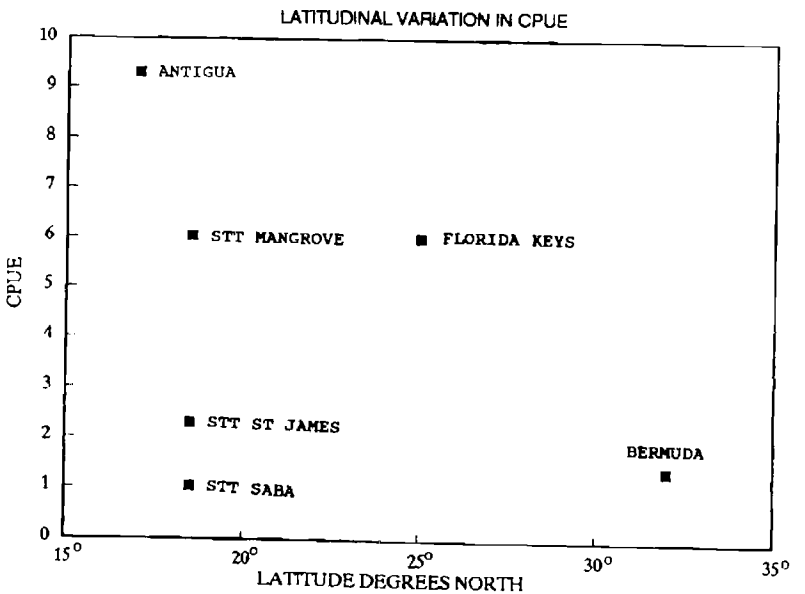

Fig. 7. Catch per unit effort in Antigua, Bermuda, Florida and St. Thomas.

THE DEVELOPMENT OF PEST RESISTANT TRANSGENIC PLANTS

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ABSTRACT

The status of the development of pest-resistant transgenic plants was reviewed with primary focus on insect resistance. Such plants are genetically altered by recombinant DNA to exhibit resistance to one or more pest species. Bacterial plasmids such as found in Agrobacterium tumefaciens have proven to be effective vectors for introducing desired genes into DNA of selected host plant species. Genes have been success-fully transferred by both protoplast and intact cell wall transformation. Transfer techniques include: (1) Agrobacterium tumefaciens - mediated transfer of genes, (2) micro-injection of genes into cell nuclei, (3) protoplast-dependent direct transfer of genes, and (4) particle gun techniques (biolistics) whereby tungsten or gold particles coated with DNA are propelled under high velocity into intact plant cells. The gene for insect control in Bacillus thuringiensis has been isolated and success-fully inserted into the DNA of plant cells of cotton and potatoes for control of certain Lepidopteran and Coleopteran insects. Similar investigations are being conducted on other plants including tomato, maize, and tobacco. Two concerns regarding development of insect-resistant transgenic plants are the potential for insects to develop resistance and the receptivity of the general public to use such plants for human consumption.

INTRODUCTION

Concerns regarding human health and the environment have led to increased levels of research on alternatives to using chemical pesticides. The age of chlorinated hydrocarbons, organophosphates, and carbamates is gradually giving way to new strategies of pest management. One of these is the increased interest in the use of biological agents such as Bacillus thuringiensis. This is a naturally occurring soil bacterium which produces proteins used in controlling certain insects. Initially this material was used only for control of certain Lepidopteran insects. Further research has led to the discovery of additional endotoxins or strains of this bacterium that have shown efficacy against certain members of the orders, Diptera and Coleoptera.

Genetic engineering for development of pest-resistant plants is perhaps one of the most remarkable strategies on the horizon at the present time. It is envisioned there will be substantial advances in this area during the next 10 to 15 years. The feasibility of developing transgenic plants resistant to certain insects and disease pests has already been demonstrated. For example, genetic material from the bacterium Bacillus thuringiensis has successfully been incorporated into the genetic complement of plants to impart resistance against certain insects. The potential in developing transgenic plants, however, extends far beyond just pest-resistance characteristics. Researchers continue to map genes to discover the traits each gene determines. Consequently, undesirable genes can be isolated and replaced with desirable ones.

METHODS AND MATERIALS

Transgenic plants have been genetically altered by recombinant DNA. This involves isolating specific genes, moving them from one organism to another and then creating new

combinations of genes which can be repro-duced in quantity. Four techniques for transferring genes in the develop-ment of transgenic plants are: (1) Agrobacterium tumefaciens - mediated transfer of genes, (2) micro-injection of genes into cell nuclei, (3) protoplast-dependent direct transfer of genes, and (4) use of particle gun techniques referred to as biolistics (Potrykus, 1992).

Bacterial plasmids such as the Ti plasmid found in Agrobacterium tumefaciens have proven to serve as effective vectors for introducing desired genes into DNA of selected host plant species. Plant tissues used are generally explants derived from cotyledons, hypocotyls, leaves, roots, stems, tubers, etc. Single-cell protoplasts may also be used. Trans-formed plant cells are then placed on a selective medium and allowed to develop into transgenic plants. Monocotyledonous plants generally are not sensitive to Agrobacterium tumefaciens infection (Angenon and Montagu, 1992).

Restriction enzymes (which can be isolated from various bacteria) are able to cut DNA molecules at very specific locations or sequences of nucleotides. The location depends upon the enzyme used. The cut ends of the DNA strands are referred to as being sticky (chemically speaking) and therefore readily attach to each other forming recombined molecules (Monsanto, 1992).

Micro-injection of genes involves use of a fine glass capillary tube inserted into the nuclear envelope of the protoplast. During the procedure, the protoplast needs to be immobilized (Weissinger, 1992). Micro-injection through intact plant cell walls has also been reported (Singh and Shaw, 1992).

Protoplasts have the cell wall removed and therefore take up DNA more readily. The direct transfer of genes in this technique is facilitated chemically by use of polyethylene glycol or calcium phosphate. Electroporation is also used sometimes to facilitate uptake of DNA. Transient pores are formed in the plasma membrane as a result of a short pulse of high voltage electricity (Singh and Shaw, 1992).

Particle gun techniques involve the use of microscopic tungsten or gold particles coated with DNA. These particles are then propelled through intact plant cell walls and plasma membranes at high velocity. Compressed helium or compressed air may be used as propellants (Weissinger, 1992).

RESULTS AND DISCUSSION

A number of transgenic plants where Agrobacterium tumefaciens has been used as the vector include: celery, sugar beets, oilseed rape, muskmelon, cucumber, strawberry, soybean, cotton, sunflower, walnut, lettuce, flax, tomato, apple, alfalfa, tobacco, petunia, pea, aspen, poplar, eggplant, and potato (Angenon and Montagu, 1992). Genes introduced into the above plants were done so to impart various characteristics. The development of transgenic plants for insect resistance is still in its infancy; however, a number of initiatives are in progress.

The gene for insect control in Bacillus thuringiensis has been isolated and successfully inserted into the DNA of plant cells of cotton and potatoes for control of certain Lepidopteran and Coleopteran insects. Excellent resistance to pink bollworm was reported for three transgenic cotton lines containing Bacillus thuringiensis (Wilson, et al., 1992). Field testing done at The Ohio State University on transgenic Russet Burbank potatoes containing Bacillus thuringiensis ä endotoxin, yielded excellent control of Colorado potato beetle (Hoy, 1994). Research is also being done by industry on the development of insect-resistant transgenic tomato, maize, and tobacco plants.

Transgenic cowpea plants containing Bacillus thuringiensis genes for insect resistance have been tested (Murdock, 1992). The potential for further development of pest-resistant transgenic plants, in general, is very promising.

Concerns include: (1) the potential for insects to develop resis-tance to transgenic plants, (2) the receptivity of the general public to use such plants for human consumption, (3) the possible escape of genetic material from transgenic plants into wild plant populations, (4) the food safety issue, and (5) government regulations concerning development and use of transgenic plants.

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DEVELOPMENT OF *PANICUM SP.* HYBRIDS USING APOMICTIC PLANTS

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ABSTRACT

Guineagrass (*Panicum maximum* Jacq.) is an excellent forage grass. One of its major weaknesses is its seed shattering and low seed yield. Efforts to increase seed retention in guinea-grass have been unsuccessful due to the lack of genetic material having this characteristic and also to the difficulty encountered in the hybridization process. The reproduction of guineagrass is based on aposporous apomixis with pseudogamy. For the development of *Panicum* hybrids, we utilized facultative apomictics and two germplasm sources previously discovered. A possible hybrid was obtained using facultative apomictics PI 277901 and CIAT 673. Utilizing RAPD analyses, the following hybrids (2n=32) were verified: SPM-92 x PRPI 3622 and Tift-49 x PRPI 3622. Natural and hand-made crosses of paragrass (*P. purpurascens* Raddi) x klein-grass (*P. coloratum* L.) (2n=36) were also verified utilizing RAPD analyses. This study reports for the first time the existence of new Panicum hybrids including an interspecific hybrid of para x klein grass and the utilization of RAPD's as an excellent tool for the verification of the existence of hybrids in the Panicums.

INTRODUCTION

Probably the most important representative of the Panicums is guineagrass (*Panicum maximum* Jacq.), a warm-season perennial bunchgrass. Besides being adapted to many ecological conditions in the tropics and subtropics the high yielding potential of this forage is well known. Guineagrass reproduces by aposporous apomixis with pseudogamy and the progenies are genetically similar to those of the mother plants although sexual plants have been discovered in populations of several introductions (Burton, et al. 1973). The method of reproduction of guineagrass and other related apomictic species might explain the absence of hybrids that have been reported in the Panicums.

In Florida, Smith (1972) discovered the existence of sexual plants in *P. maximum* populations of PI 156542, 277901 and 277962 while in Georgia, Burton et al. (1973) discovered two sexual plants in facultative apomictic introductions, PI 277946 and 277922. These five different cytoplasms could probably offer alternatives for the use in the development of hybrids or to reduce the genetic vulnerability of the genus. In Georgia, Hanna (1993) developed and released a sexual clone of *P. maximum* (Tifton SPM92) which has great potential in a breeding program.

One of the objectives of our breeding program is to reduce seed shattering in guineagrass (2n=32) which could be accomplished by transferring seed retention from a related species, *Panicum coloratum* L. (kleingrass) (2n=36). Since the two species differ in chromosome number, we do not expect them to cross through regular breeding methods. An additional alternative that we are exploring is the evaluation of advanced generations of crosses between sexual x apomictic plants, which might release the genes for resistance to shattering.

Another related species of guineagrass is *P. purpurascens* Raddi, known as paragrass or "malojillo." It is a native of Africa, from where it was introduced into Brazil (Hitchcock, 1935). Paragrass is a vigorous, stoloniferous species with stems reaching a length of 1.8 to 4.7 meters, and generally rooting at the nodes. It is widely found in moist and poorly drained soils, and if managed properly can produce abundant forage (Alberts and García-Molinari, 1943). Kleingrass and paragrass, having the same chromosome number (2n=36), offer an excellent opportunity to study the inheritance of

seed shattering present in kleingrass. This study reports basic cytology work of some breeding accessions of *P. maximum* and the characterization of parents and hybrids using cytogenetic and molecular techniques.

MATERIALS AND METHODS

The plants used in this study as female parents were Tifton *Panicum maximum* 49 (Tift PM49), Tifton sexual *Panicum maximum* 92 (Tift SPM92), Borinquen, and a series of lines previously identified as potential sexual plants discovered in facultative apomictics by Burton et al. (1973) and Smith (1972). As compared to the common guineagrass, cultivar Borinquen is a more delicate grass than other Panicums and contains a high leaf to stem ratio. The Borinquen plant material used in the breeding program was collected by the senior author in the city of Mayaguez near highway number 2.

During 1993 crosses were made in the greenhouse at TARS, Mayaguez, Puerto Rico and under field conditions at the Isabela ARS farm. Panicles of the female parents approaching flowering, were covered with plastic bags in late afternoon and removed next morning at sunrise. Exserted stigmas between the non-dehiscing anthers were dusted with pollen from the male parents and panicles were then enclosed in brown paper bags. Seed of each cross was sown on jiffy-pots containing a mixture of soil and filtered press-cake. The germinated seedlings were individually transplanted to 20 cm pots. The progeny was morphologically evaluated and biochemically analyzed to identify the presence of hybrids.

Pollen mother cells and root-tips were used to determine chromosome number. The first procedure, (Burson and Bennett, 1970), consisted of collecting and fixing immature inflorescenses in Carnoy's solution (6:3:1) to study microsporogenesis. Pollen mother cells were stained with aceto-carmine and examined using phase contrast microscopy. In the second procedure, (Hanna et al., 1973), root tips were collected in the morning (7:00-9:00), and placed in 1-bromonaphthalene for two hours. After hydrolysis in 1N HCl for 10 minutes at 60° C they were stained using Fuelgen stain, macerated on acetocarmine and observed using phase contrast microscopy.

To characterize the parents and hybrids used, DNA was extracted using the "mini-prep" procedure of Afanador et al. (1993), with modifications. In this procedure, DNA is extracted from 2"- 4" sections of the immature rolled leaf base. Six hundred microliters of extraction buffer were added to the leaf tissue in a mortar and 100 to 150 mg of sterile sand used to grind the leaf tissue. Further procedures were those used for bean DNA analyses (Afanador et al.,1993). Extracted DNA was examined using RAPD analyses (Haley et al., 1993).

RESULTS AND DISCUSSION

The examination of root tips and pollen mother cells of sixteen Panicums from the TARS collection showed a chromosome number of 2n=32 for *P. maximum* and 2n=36 for *P. coloratum* (PI 410177), *P. purpurascens* and *P. purpurascens* x *P. coloratum* (Table 1).

The progeny derived from the crosses between: a. *P. maximum* (Borinquen) x *P. coloratum* (Kleingrass) and b. *P. maximum* (PI 277901) x *P. maximum* (CIAT 673) was morphologically identical to the female parent, suggesting that self-pollination had occurred. The three other crosses made: a. *P. maximum* (SPM-92) x *P. maximum* (PI 3622), b. *P. maximum* (Tift 49) x *P. maximum* (PI 3622) and c. the interspecific cross between *P. purpurascens* (Paragrass) x *P. coloratum* (Kleingrass), produced hybrid progeny (Table 2).

The patterns generated by decamer primers of random sequence, were examined for polymorphic RAPD's between the parents that are recombined in the hybrids. Primer OAN-17 identified Tift-49 x PI 3622, SPM-92 x PI 3622, and *P. purpurascens* x *P. coloratum* (Figs. 1,2), as hybrids.

These results demonstrate the feasibilty of using RAPD's analysis as a tool for identifying hybrid progeny, in the efforts directed at solving the seed shattering problem. Recovery of an interspecific

progeny, in the efforts directed at solving the seed shattering problem. Recovery of an interspecific hybrid from the *P. purpurascens* x *P. coloratum* cross demonstrates the possibility of transferring the genes involved in seed shattering. This would permit their manipulation for the reduction or elimination of a great weakness of *Panicum maximum*.

Results from preliminary evaluations of this hybrid still indicate a tendency to seed shattering. Further crossing and evaluations are required to assess the nature of the inheritance of this trait.

CONCLUSIONS

The identification of guineagrass hybrids from crosses involving sexual and apomictic plants, increases the possibilities for the release of the genes for shatter resistance. Recovery of an interspecific hybrid from the *P. purpurascens* x *P. coloratum* cross confirms the possibility of manipulating and studying the genes involved in seed shattering. The use of RAPD's analyses as a tool for the identification of hybrid progenies will make an important contribution in the efforts to improve seed retention in guineagrass.

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Table 1. Chromosome number in sixteen selected *Panicum* accessions from TARS collection.

Plant Species and Introduction Number	Chromosome Number (2n)
1. *P. maximum* (PI 3622)	32
2. *P. maximum* (PI 156542)	32
3. *P. maximum* (PI 277901)	32
4. *P. maximum* (PI 277922)	32
5. *P. maximum* (Borinquen)	32
6. *P. maximum* (Tift PM49)[1/]	32
7. *P. maximum* (Tift SPM92)[2/]	32
8. *P. maximum* (CIAT 673)[3/]	32
9. *P. maximum* (CIAT 6171)	32
10. *P. maximum* (CIAT 6180)	32
11. *P. maximum* (CIAT 6501)	32
12. *P. maximum* (CIAT 6533)	32
13. *P. maximum* (CIAT 6567)	32
14. *P. maximum* (PI 410177)	36
15. *P. purpurascens*	36
16. P. purpurascens x P. coloratum	36

[1/] Tifton *P. maximum* 49
[2/] Tifton sexual *P. maximum* 92
[3/]Centro Internacional de Agricultura Tropical, Cali, Colombia

Table 2. *Panicum spp.* utilized as parental material.

Female Parent	Male Parent
P. maximum (Borinquen)	*P. coloratum* (Klein)
P. maximum (Tift SPM92)	*P. maximum* (PI 3622)
P. maximum (Tift PM49)	*P. maximum* (PI 3622)
P. maximum (PI 277901)	*P. maximum* (CIAT 673)
P. purpurascens (Pará)	*P. coloratum* (Klein)

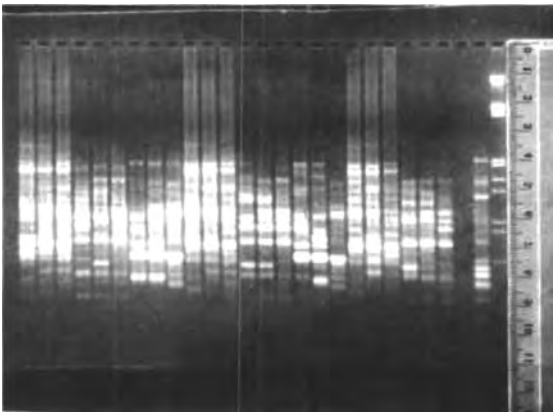

Fig. 1. Ethidium bromide stained PCR products amplified by decamer primers and separated on 1% agarose gel.

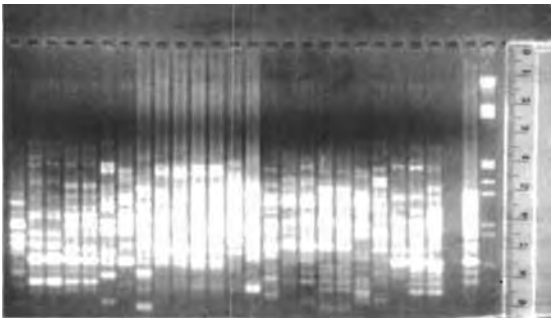

Fig. 2. Ethidium bromide stained PCR products amplified by decamer primers and separated on 1% agarose gel.

IMPROVEMENTS IN THE QUALITY OF MICROPROPAGATED *ANTHURIUM ANDREANUM* L. PLANTLETS BY THE USE OF BILAYER CULTURE TECHNIQUES: PRELIMINARY RESULTS

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ABSTRACT

Anthurium andreanum is becoming increasingly important in the Caribbean, playing a part in the agricultural diversification programs of many governments. Planting material is generally mass produced via micropropagation, during which *Anthurium* morphogenic callus is usually transferred to solid multiplication medium for shoot regeneration. The regeneration rate and the shoot quality, however, can sometimes be very poor, necessitating a prolonged culture period to produce plantlets of sufficient size and quality for weaning. The use of liquid media is known to enhance shoot regeneration in some species, but it also requires costly equipment in the form of rotary or oscillating shakers, and can induce shoot hyperhydricity (vitrification). An intermediate media form requiring no additional equipment, namely the bilayer, has many of the advantages of liquid culture with less of a tendency to induce hyperhydricity. The use of bilayer culture media was shown to stimulate and prolong *Anthurium* shoot production. Plantlets produced in this way were larger, with a greater number of leaves. The leaves, also, had a greater surface area and they appeared to be much darker green than those of the control. Further experiments indicate that these plantlets are hardier, surviving the weaning process well and quickly initiating new growth. The simple use of bilayer techniques can, therefore, be used to improve the quality of micropropagated *Anthurium* plantlets, while reducing the production time. This improved micropropagation efficiency better enables planting material produced in the Caribbean to compete with imports.

INTRODUCTION

Governments throughout the Caribbean are increasingly developing agricultural diversification programs to aid in the improvement and expansion of their agricultural export industries. A component of these programs is often ornamental crops, mainly cut flowers, which have a ready local market, including hotels, restaurants and cruise ships, while also having tremendous export potential. Tropical flowers, or 'exotics', form only a small proportion, approximately 3% (Rajkumar, 1991), of the total world trade in cut flowers. The wholesale market for *Anthurium* alone is US$17.8 million in North America and US$25.6 million in Europe (International Trade Centre, 1990) and even a small proportion of this market equates to a fairly large amount of foreign exchange.

Anthurium andreanum is an outbreeding species and can be propagated by seed, but cultivars propagated this way have poor uniformity and it can take four years, after fertilization, before the plants are large enough to be evaluated (Geier, 1990). This wide variation is invaluable to breeders but clearly unsatisfactory for mass propagation. *Anthurium* can also be propagated vegetatively by terminal cuttings, stem sections or suckers, but this method is again unsatisfactory for mass propagation as the multiplication rates are low. Micropropagation techniques have been successfully applied to *Anthurium* and they are now generally mass produced in this way. In the Netherlands alone, over half a million *Anthurium* plants are produced by micropropagation per year (Pierik, 1991).

A number of alternative micropropagation schemes, with varying degrees of success, have been proposed, firstly by Pierik *et al.* (1974) and then Kunisaki (1977, 1980) and Leffring and Soede

(1978, 1979a,b). These have been refined over the intervening years and are summarized by Geier (1990) in Figure 1.

Morphogenic callus tissue is generally transferred to solid multiplication medium for shoot regeneration. These shoots are removed and transferred either to root induction media or to multiplication media for further growth. The remaining clump of callus tissue and shoot initials is returned to fresh multiplication media for further development and shoot production. Shoots cannot be induced to form indefinitely from this clump and the rate of shoot production decreases dramatically after four to five subcultures (Geier, 1990; Personal observation - results not presented).

A series of experiments was performed with three initial aims: to increase the rate of shoot formation from *Anthurium* callus; to increase the number of subcultures from which good quality shoots could be obtained; and to assess the improvement, if any, in the quality of these shoots.

The physical characteristics of the media were manipulated in order to stimulate and prolong shoot production. A number of workers have used liquid culture as part of an *Anthurium* micropropagation scheme, including Leffring and Soede (1979b) and Kunisaki (1980). The use of liquid media is known to enhance shoot regeneration in some species (Chu *et al.*, 1993; Paranjothy, 1984; Short, 1986), but this requires costly equipment, in the form of rotary shakers, and can in some cases induce shoot hyperhydricity (Debergh *et al.*, 1992), whereby the shoots become unusable. An intermediate media form requiring no additional equipment, namely the bilayer, has many of the advantages of liquid culture with less of a tendency to induce hyperhydricity.

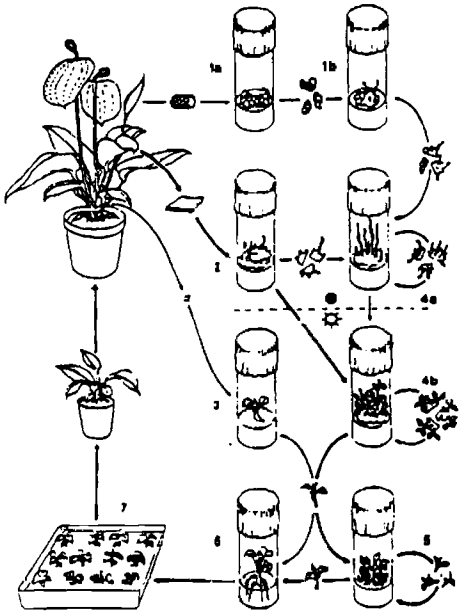

Fig. 1. Micropropagation of *Anthurium*. (1a,b) Establishment of caulogenic callus from spadix sections. (2) Establishment of caulogenic callus from leaf sections. (3) Shoot establishment from axillary bud explants. (4a) Multiplication of caulogenic callus in darkness. (4b) Multiplication of caulogenic callus under illumination. (5) Multiplication of isolated shoots by shoot proliferation. (6) Rooting of isolated shoots. (7) Establishment of plants in soil or potting mix.

MATERIALS AND METHODS

A range of culture media for *in vitro* multiplication of *Anthurium*, mainly based on Murashige and Skoog (1962), are being used at the CARDI Tissue Culture Laboratory, Barbados. There appears to be a varietal response to nitrate levels in the media (data not presented) which has also been noted by other workers (Geier, 1990; Kuehnle and Sugii, 1991), however, one media (lab code - MS2) has shown good results with many of the varieties under test and, therefore, was used for this series of experiments.

The multiplication media, MS2, was as Murashige and Skoog (1962) supplemented with sucrose (20 gl^{-1}) and benzylaminopurine (0.25 mg l^{-1}). Media was placed in Magenta culture vessels (Sigma Chemical Co., USA) either in the form of 50 ml solid media (containing 7gl^{-1} agar), 50 ml liquid media (on a rotating bed) or a bilayer of 25 ml solidified media overlaid with 25 ml liquid media.

Five morphogenic callus clumps each of the varieties Hybrid Red and Hybrid Pink var.2 were used. Each clump was approximately 2 cm in diameter and was divided into three equal pieces which were placed in solid, liquid and bilayer culture conditions. After 4 weeks each clump was hedged of all shoots larger than 0.5 cm. These were transferred to multiplication media for further growth and multiplication. The remaining clump of callus and shoot initials was placed in fresh MS2 media. This cycle was continued until no further usable shoots were obtained. Shoots showing hyperhydricity, fasciation or an abnormal appearance were discarded and not recorded.

In the second experiment four varieties were used, namely Hybrid Pink var.2, Hybrid Red, Common Pink and Hybrid Pink var.1. For each variety, ten large clumps (approximately 4 cm diameter) consisting of morphogenic callus, shoot initials and very small shoots (less than 0.5 cm) were used. These were each equally divided and one half placed on 50ml of solidified MS2 media in a Magenta container. The other half was placed in a Magenta container with a MS2 bilayer (25 ml solid / 25 ml liquid).

The clumps were allowed to grow and multiply for 8 weeks, after which all shoots over 1 cm high were removed. Out of these, 20 shoots per variety per production system were randomly selected and their leaf surface area measured.

RESULTS AND DISCUSSION

The shoots produced by both Hybrid Pink var.2 and Hybrid Red in weeks 4, 8 and 12 generally showed no morphological abnormalities and were used for further micropropagation; however, in weeks 16 and 20 there were many more distorted shoot initials. These were discarded and this is reflected in the low numbers of usable shoots for these weeks (Table 1). The reduced quality of shoots did not appear to correlate with any media type; they were all morphologically abnormal and no hyperhydricity was seen, even in the liquid cultures.

The use of bilayer or liquid media, instead of the more conventional solid media, resulted in a greater number of usable shoots being produced, with the production continuing over a slightly longer time period. In these respects, also, use of the bilayer media form was an improvement over the liquid media.

There appears to be varietal differences in the numbers of usable shoots produced. This may relate to the varying varietal growth responses to different media compositions (Geier, 1990; Kuehnle and Sugii, 1991) and for each variety the media may have to be designed specifically in order to maximize the growth responses.

Table 1. Shoot Production from Callus Clumps of Hybrid Red and Hybrid Pink var.2.

Variety	Media Type	Number of shoots removed at:					
		Week 4	Week 8	Week 12	Week 16	Week 20	TOTAL
Hybrid Red	Solid	mean = 4.4 sd = 0.55	mean = 3.0 sd = 1.22	mean = 1.2 sd = 0.84	mean = 0.4 sd = 0.55	mean = 0.0 sd = 0.00	mean = 9.0[a] sd = 1.87
	Bilayer	mean = 9.4 sd = 0.89	mean = 6.2 sd = 1.30	mean = 4.6 sd = 0.89	mean = 2.0 sd = 0.71	mean = 0.8 sd = 0.84	mean = 23.0[b] sd = 1.22
	Liquid	mean = 7.2 sd = 0.84	mean = 4.4 sd = 1.67	mean = 2.0 sd = 0.71	mean = 1.2 sd = 0.45	mean = 0.2 sd = 0.45	mean = 15.0[c] sd = 2.55
Hybrid Pink var.2	Solid	mean = 2.6 sd = 0.55	mean = 1.8 sd = 0.45	mean = 1.0 sd = 1.0	mean = 0.2 sd = 0.45	mean = 0.0 sd = 0.00	mean = 5.6[d] sd = 2.07
	Bilayer	mean = 6.0 sd = 0.71	mean = 4.0 sd = 1.0	mean = 3.6 sd = 0.89	mean = 1.2 sd = 0.84	mean = 0.2 sd = 0.45	mean = 15.0[c] sd = 2.92
	Liquid	mean = 5.4 sd = 0.55	mean = 3.8 sd = 0.84	mean = 2.8 sd = 1.30	mean = 1.4 sd = 1.14	mean = 0.2 sd = 0.45	mean = 13.6[f] sd = 3.85

Results with differing superscripts are significantly different ($p<0.05$) using ANOVA performed on transformed data.

Shoot production from callus can, therefore, be improved by using a liquid or bilayer system, with the latter eliciting the most improvement. Liquid culture usually necessitates the use of a shaking bed to keep the cultures aerated and this can be an expensive piece of equipment, especially for a small laboratory. It is heartening, therefore, to see that by the simple use of bilayer techniques the advantages of liquid culture can be gained without the extra equipment costs. Consequently the bilayer technique has been introduced into the standard *Anthurium* micropropagation protocol used at the CARDI Tissue Culture Laboratory.

It was noted that the shoots produced in the bilayer system appeared to possess larger, darker green leaves than those in the conventional (solid media) system. Preliminary experiments are underway to quantify those factors which are perceived to indicate improved shoot quality. There was also a need to study the effects of the technique on other varieties and so further work continued with the addition of the varieties Common Pink and Hybrid Pink.

The leaf surface areas of shoots produced in the conventional (solid media) system and in the bilayer system were measured. The preliminary results are shown in Table 2.

Table 2. Leaf surface area of plantlets produced in the conventional and bilayer production systems.

Variety	Leaf surface area - conventional system	Leaf surface area - bilayer system	Percentage increase in leaf area
Common Pink	mean = 0.14cm² sd = 0.06cm²	mean = 0.78cm² sd = 0.28cm²	457%
Hybrid Red	mean = 0.13cm² sd = 0.09cm²	mean = 0.71cm² sd = 0.13cm²	446%
Hybrid Pink var.1	mean = 0.14cm² sd = 0.11cm²	mean = 0.52cm² sd = 0.15cm²	271%
Hybrid Pink var.2	mean = 0.12cm² sd = 0.10cm²	mean = 0.58cm² sd = 0.11cm²	383%

The results from each variety and system have been expressed as means with standard deviation. As a preliminary comparison, for each variety, the leaf surface area using the bilayer system has been expressed as a percentage increase over that of the conventional system. Further results will be gathered before full statistical analysis is performed on the data.

As a preliminary observation, therefore, the use of a bilayer system increases the leaf surface area of shoots in the range of 271 - 457%, depending upon variety. This increased growth

response may be due, in part, to an improved diffusion and uptake of nutrients or growth hormones. The bilayer liquid phase may be more chemically homogeneous, thereby preventing a hormone- or nutrient-deficient 'halo' around the plantlet. The solid phase may also act as a type of slow-release reservoir for hormones or nutrients, thus allowing them to be supplied to the plantlets in a more controlled manner. It must be stressed that these are preliminary deductions and much more work is required before full conclusions can be drawn.

It was noted as a purely subjective observation that the shoots produced in the bilayer system appeared to have leaves that were of a much darker green. Plantlets *in vitro* are generally not fully photosynthetically competent (George and Sherrington, 1984) and an increased chlorophyl content does not necessarily relate to increased photosynthetic activity , however, it does suggests an interesting line of research. It is difficult to easily obtain information about the potential chlorophyll activity and photosynthetic competence of the plantlets but a measurement of the CO_2, O_2, RubisCO or other enzyme activity (Dai *et al.*, 1990; Husemann *et al.*, 1990; Kozai, 1990) would provide an indication as to the photoautotrophic status of these plantlets.

As a further subjective observation it was noted that plants produced in the bilayer system appeared to suffer less stress during the weaning process. There were less losses and the plants appeared to recover more quickly. It is possible that these plants can be weaned without a prior *in vitro* rooting stage, hence reducing the time and expense of the production process. A number of experiments are underway to quantify these observations.

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MICROPROPAGATION AND FIELD PERFORMANCE OF VIRUS-FREE WHITE COCOYAM (*XANTHOSOMA SAGITTIFOLIUM* L. Schott) IN COSTA RICA

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ABSTRACT

Apical meristem (dome with one or two leaf primordia) explants of a local virus infected white cocoyam were culture on modified Murashige and Skoog (MS) medium containing 0.1 mg. L^{-1} 6-Benzylaminpurine (BA). After 120 days, complete plants were developed and above 90% of them were Dasheen Mosaic Virus (DMV) free according to ELISA test. To induce axillary shoot formation, corm section of *in vitro* plants were culture on modified MS medium supplemented with 3 mg L^{-1} 6-BAP. An average of 4 shoots were formed every 42 days. Shoots produced *in vitro* were rooted on MS without growth regulators with 100% success and after 42 days, complete plants were obtained. About 98% of the rooted *in vitro* plants survived transfer to the greenhouse and were successfully transplanted outdoors. Field evaluation of two generations of *in vitro* virus-free white cocoyams was done. The results indicated that virus-free white cocoyams had twice the yield and better cormel quality than virus-infected plants. The establishment of a certification 'seed' program for white cocoyam is discussed.

INTRODUCTION

Edible aroids, cocoyam (*Xanthosoma* spp), taro (*Colocasia esculenta* (L) Schott) and edible yams (*Dioscorea* spp), represent an important source of food for the developing world. They are an important staple food in Africa, the Caribbean, Asia and many Pacific islands (O'Hair and Asokan, 1986; Volin and Zettler, 1976). In spite of their fundamental role in the diets of many people in these areas, little research has been done on them and the policy makers and researchers have only recently become interested in them (Gómez, 1994 personal communication).

After its nomination as non-traditional crop, the cocoyam production area and exports were expanded. According with the Costa Rican goverment data, the total production area was increased from 359 to 1023 ha in nine years (1983 to 1992). Consequently, exports increased from 540 to 5, 661 metric tons in the same period. The estimated value increased from US $ 214,121 to 3, 567,000 (Rodríguez, 1993). The main export markets have been The United States (Latin American and Oriental communities), Puerto Rico, and other countries, such as Canada, Holland and England.

Cocoyam like most cultivated aroids, is propagated exclusively by vegetative means, using cormels and corm sections. Therefore, it is very sensitive to virus and other pathogens, which are transmitted with the propagation material.

Due to continued asexual propagation of edible aroids, growers are experiencing serious disease losses. Dasheen Mosaic Virus (DMV) is the most important virus disease. DMV has been found around the world associated with all edible aroids (Zettler and Hartman, 1986). It has been detected in Florida (Hartman 1974,) Egypt (Abo El-Nil and Zettler, 1976), Venezuela (Debrot and Ordosgoitti, 1974) and Costa Rica (Monge and Arias, 1984).

DMV belongs to the potyvirus group, its size is around 750 nm, is aphid-transmitted in a stylet-borne manner and it induces citoplasmatic inclusions (Zettler *et al.*, 1970; Abo El-Nil, Zettler and Hiebert, 1977). DMV symptoms on leaves include "feathering," mosaic and distortion. Their expression depends on the genotype and the season in which it is grown. Normally they are

intermittently expressed, which make the virus difficult to detect (Zettler and Hartman, 1986; Hartman, 1974).

In Costa Rica, the DMV occurs in at least 80% of all commercial plantations (Ramírez, 1983). Preliminary studies on yield and quality of white and purple cocoyam, showed that plants with symptoms yielded 25% and 41% less, respectively, than non-symptom plants (Monge and Arias, 1984).

Root-rot, known as 'mal seco' in Puerto Rico and Costa Rica and cocoyam or tannia leaf-burning disease in the English-speaking Caribbean, is the most serious disease on *Xanthosoma* production in Africa, the Caribbean and now in Costa Rica. Potentially contaminated soil on the propagules and systemically infected planting material carried from one planting region to another are the two major ways the disease spreads. The cause of this root rot has been extremely difficult to identify because it is a soil borne disease, and speculation has prevailed in the absence of research. Nzietchueng (1983) and Rodríguez-Marcano and Rodríguez-García (1986) found that *Rhizoctonia solani* and *Phytium* and *Fusarium* spp. which are commonly found in soils, seem to be causal agents of root-rot disease. However, cocoyam root-rot in Cameroon, possibly the same disease, is caused by *P. myriotilum* (Nzietchueng, 1985). In Costa Rica, bacteria of the genera *Erwinia* and *Pseudomonas* has been associated with the disease (Vargas, 1989; Bosque-Vega, 1991).

In Puerto Rico, Dominican Republic and Costa Rica as well as Cameroon, cocoyam production has been steadily declining as a consequence of this disease and has reduced yields up to 90% in some cocoyam plantations. A strategy to control mal seco is urgently needed. Clean 'seed' is an important part of this strategy.

Tissue culture techniques have been shown to be an effective alternative for producing large amounts of pathogen- free cocoyam planting material (Hartman, 1974; Salazar *et al.*, 1985; Gómez *et al.*, 1989 and Zettler *et al.*, 1991). However, the unit cost per tissue culture plant is high for direct use as planting material and the rapid reinfection limits the use of the new technology.

A more cost effective approach to produce *Xanthosoma*, whereby the benefits of micropropagation can be realized, is through the establishment of mother blocks, where pathogen-free stocks can be grown in areas with little inoculum pressure and ultimately released as certified stock for planting. This study was designed to show the results of a research program on producing cocoyam pathogen-free planting stock through tissue culture technique and field multiplication on mother blocks.

MATERIAL AND METHODS

Plant material and surface sterilization

Shoot-tips were excised from plants of (*Xanthosoma sagittifolium* L Schott) collected in the Atlantic area of Costa Rica. Shoots were trimmed to approximately 2 cm^3 rinsed in flowing tap water, submerged 15 min in 1.25% sodium hypochlorite and rinsed three times in sterile distilled water in an aseptic room.

In vitro culture

With the aid of a dissecting microscope, each shoot was then trimmed until only the apical dome and one or two primordial leaves remained. Finally, each shoot was transferred to 18 x 150 mm test tubes containing 10 ml of establishment medium composed of Murashige and Skoog (MS) medium (Murashige and Skoog, 1962) plus 0.1 mg. L^{-1} 6-benzylaminopurine (BA), 3% sucrose and 0.18% gelrite. For axillary bud development, explants were cultured in a 125 ml baby food jar containing 25 ml multiplication medium composed of MS plus 3 mg. BA, 3% sucrose and 0.18% gelrite and for plantlet growth, explants were cultured in a 200 ml baby food jar containing 25 ml of a MS medium without growth regulators plus 4% sucrose and 0.18% gelrite. The pH was adjusted to 5.7 before autoclaving for 15 min at 121 °C. Explants were cultured at 23 ± 2 °C under 12 hr photo-

period. The light source was cool white fluorescent tubes (Phillips 60W) providing 50 imol . m^{-2}. s^{-1}.

Greenhouse culture

Plantlets were removed from the baby food jars and washed thoroughly with tap water to remove the gelled medium from the roots. They were submerged 30 seconds in a solution containing 5 ml Kilol L DF-100 and 1 ml Phosphorus per liter and transplanted to 72 compartment plastic trays, filled with sterilized substrate composed of soil and coconut fibre (1:1).

Plantlets were grown in the greenhouse under a plastic tunnel with intermittent mist (> 80% RH). Three days after transplanting and every weeks thereafter, the plantlets were fertilized (foliar applications) using 20:20:20 ($N:P_2O_5:K_2O$). Fertilizer mixed with water at the rate of 5 g L^{-1}. After three weeks, plantlets were moved from the plastic tunnel to a bench. The plants were ready for moving to the field four weeks after they were removed from the baby food jars.

Field establishment

At the field location the plastic trays with the plants were placed in shelter covered with plantain or palm leaves ('rancho'). After one week, they were removed from the plastic trays and transplanted to a polyethylene bags filled with 1 Kg. of soil and 10 g of 10:30:10 ($N:P_2O_5:K_2O$) granular fertilizer. The plants were ready for transplanting to the field three weeks after the shipment arrived.

Field experiment

One experiment was performed on a traditional production area (Los Diamante research station, Guápiles) from Nov. 1987 to Sept. 1988. Four treatments; 1. *in vitro* plants, 2. second generation planting material, cormels from *in vitro* plants and 3. third generation planting material, cormels from second generation of *in vitro* plants and 4. planting material (cormels) from local commercial plantations, were arranged in a randomized complete block design with four replications on 44 plants per plot.

Additional experiments were established on non-traditional production areas. One was set up on Bagaces, Guanacaste from Nov. 1989 to Nov. 1990 with 1000 *in vitro* plants. Another experiment was performed at Naranjito research sub-station, Quepos from Sept. 1990 to Nov. 1991. Two harvest treatments, 12 and 14 months, were arranged in a randomized complete block design with two replications on 250 *in vitro* plants per plot.

The plant spacing for the Guápiles experiment was 1 x 0.5 m, about 20,000 plants ha^{-1}. The distance for the Bagaces and Naranjito experiments was 1.5 x 0.4 m, about 16,666 plants ha^{-1}.

Guápiles site

Los Diamantes research station is located in the Atlantic zone, known as Limón. The mean monthly rainfall was 355 mm, the average daily temperature was 26 °C and 86% relative humidity. The soil texture was loam with good fertility.

Bagaces site

The Bagaces experiment was carried out in a private farm in the north-wester zone, known as Guanacaste. The mean monthly rainfall was 166.6 mm, the average monthly minimum and maximum temperature were 18.5 and 32.1 °C and 73.4% relative humidity. The soil texture was loam with good fertility.

Naranjito site

The Naranjito research sub-station is located in the South Pacific zone, known as Quepos. The mean monthly rainfall was 382.8 mm, the average daily temperature was 28 °C and 80% relative humidity. The soil texture was loam with low fertility.

Field practice

The Guápiles experiment was fertilized with 600 Kg. ha^{-1} of a 10:30:10 ($N:P_2O_5:K_2O$) granular fertilizer. The fertilizer was applied at the rate of about 200 Kg. ha^{-1} at planting, 1 and 2 months after planting. The Bagaces experiment was fertilized with 332 Kg. ha^{-1} of 10:30:10 granular fertilizer, which was applied at the rate of about 166 Kg . ha^{-1} at 1 and 3 months after planting. At the Naranjito experiment, 471.6 Kg. ha^{-1} of 10:30:10 was employed one month after planting and after the third month, 471.6 Kg. ha^{-1} of 20:3:20 was added.

Hand and chemical weed control was applied to all the experiments.

Data collection

The plants were measured for cormel production or yield, which was divided on exportation, local market and animal feed according to González classification (González, 1987) and corm diameter, weight and length. In addition, plants also were measured for DMV and 'mal seco' infection. Visual evaluation and ELISA test were carried out to evaluate DMV infection.

RESULTS AND DISCUSSION

***In vitro* responses**

The attempt to culture pathogen-free plants of white cocoyam was successful. Within 16 weeks, shoot-tips developed into a plantlet with roots. Then each plantlet was tested for DMV infection using the ELISA test and 90% of them were virus-free.

For axillary bud development, virus free plantlets were trimmed at 1.5 cm from the corm-like structure. Then four explants were placed into a baby food jar containing 25 ml of multiplication medium. After six weeks, an average of four well developed axillary buds per explant was obtained. Then, each axillary bud was transferred to basal medium lacking growth regulators for rooting and growth. After six weeks, a well developed plantlet was produced. Then, plantlets can be recultured for axillary bud development or transferred to a greenhouse.

Field experiments

Preliminary experiments on cocoyam production areas showed that 100% of virus-free plants could be reinfected after a year. Therefore, 45% yield reduction was observed between reinfected plants and clean stock (data not shown).

The severity of DMV and 'mal seco' was reported in Table 1 for three generations of pathogen-free planting stock and a commercial 'seed'. The results showed that DMV severity did not increase in plants, which came from clean planting material (*in vitro*); however, it increased in plants which came from a commercial plantation (Table 1). The 'mal seco' severity increased during the evaluation time, in which plants from the commercial plantation were more affected (Table 1). The yield of all the treatments were affected by the DMV and 'mal seco' disease (Table 2). However, plants from clean stock showed higher total yield and marketable cormels than those from the commercial plantation.

The low yield obtained by first generation (*in vitro* plants) and from commercial stock

could be explained by 'mal seco' infection. Experiments with infected soil showed a rapid root destruction on *in vitro* plants, which lead to their death (data not shown). Planting material from the commercial plantation was already infected with 'mal seco.' Therefore, a rapid infection occurred affecting the plant development and yield.

The results of this experiment has shown the necessity of using pathogen-free planting material in order to get better yield. However, clean planting stock can not be produced on traditional producer zones due to DMV and 'mal seco' reinfection. Therefore, the establishment of mother blocks, where pathogen-free plants can be grown in isolated areas, were recommended.

Two isolated regions were selected to establish the first mother blocks for cocoyam pathogen-free production. The first area was located in Guanacaste, a dry area. During the experiment, no visual DMV and 'mal seco' symptoms were observed. In addition to that, ELISA tests were carried out on approximately 5% of the plants. All tested plants showed negative results.

The total yield was 0.88 Kg. plant^{-1}, about 14.6 ton ha^{-1}. The marketable yield (exportation cormels) was 7.69%. In addition to yield parameter, the average corm head length, diameter and weight per plant was 13.89 cm, 7.99 cm and 0.84 Kg. respectively.

The low yield of this experiment could be due to several factors, such as the cormels sprouting. Most of the cormels sprouted and average of 11 sprouts per plant was reported. Another factor was the leaf destruction due to strong wind, which may have affected the plants photosynthetic rate. The last factor was water stress. During the experiment, a drought was reported. Therefore, the plants were irrigated three times a week for 2 hrs a day with a sprinkler system. However, it may not have been enough to fulfill the plant water requirements. Water stress has been reported as one of the main causes of low cocoyam yield and its quality decreases in areas with low rainfall rates (O'Hair and Asokan, 1980; Silva and Irizarry, 1980; Onwueme, 1978).

The other non-traditional producer area evaluated was at Quepos, the Naranjito site. During the 14 months evaluation period, no DMV or 'mal seco' symptoms were observed and a sample of 10% of the total plants was selected for ELISA test. All of them were virus-free plants. In addition to ELISA test, 50 corm heads were taken for pathogen isolation tests, but none of them were reported as a 'mal seco' infected plant.

The harvest time (12 and 14 months) affected the total yield, cormel quality and corm head measurements (Table 3 and 4). Plants harvested at 12 and 14 months showed a total yield of 2.12 and 2.62 Kg. plant^{-1}, about 35.3 and 43.7 ton. ha^{-1} respectively. This means an increase of 8.1% on total yield, about 8.4 ton. ha^{-1}, on plants harvested at 14 months. These plants showed a 7.1% increase on exported type cormels and a 3.81% decrease on waste or animal feed cormels. In addition to yield parameter, the corm head length and weight also increased on those plants 19.1 and 7.4% respectively, but a decrease of 8.1% of corm head diameter was reported in respect to plants harvested at 12 months (Table 4).

In conclusion, research has demonstrated conclusively the potential benefits of micropropagation for cocoyam pathogen-free production. However, the direct production of cocoyam planting stock through micropropagation is too expensive and therefore, small farmers can not get this type of material. Consequently, the establishment of isolated mother blocks for pathogen-free cocoyam production is an alternative to reduce the cost and to transfer the planting stock to small farmers.

A Costa Rica certification cocoyam pathogen-free program can be established, in accordance with the results presented in this paper. However, the application of this program will depend on a governmental decision.

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Table 1. DMV and 'mal seco' severity evaluation of three generations of pathogen-clean and a commercial planting material. Guapiles, 1988.

Treatments	Time after planting (months)					
	3		6		9	
	DMV	MS[1]	DMV	MS	DMV	MS
1st Genera.	2.4	2.0	2.1	3.0	2.1	4.2
2nd Genera.	2.6	2.0	2.2	3.0	2.2	4.0
3rd Genera.	2.4	1.0	2.3	2.3	2.2	3.0
Commercial 'seed'	2.9	3.5	3.1	4.5	4.0	4.8

[1]Mal Seco
Escape 1 - 5

1. No visual symptoms
2. Feathering on one leaf for DMV
   Yellow leaves for 'mal seco'.
5. Feathering on more than two leaves or leaf deformed for DMV
   Plant with just one yellow leaf alive for 'mal seco'

Table 2. Yield, by categories and total yield (ton ha^{-1}) of three generations of pathogen-clean and a commercial planting material. Guapiles, 1988.

Treatments	Yield (ton ha^{-1})[1]			
	Exportation Market	Local Market	Reject	Total Yield
1st Generat.	0.31	2.4	2.41	5.12
2nd Generat.	2.28	4.29	3.67	10.24
3rd Generat.	6.83	6.40	2.65	15.88
Commercial 'seed'	0.00	0.59	0.96	1.55

[1]2000 plants ha^{-1}

Table 3. Yield, by categories, total yield (ton ha^{-1}) of *in vitro* white cocoyam harvested at 12 and 14 months after planting. Quepos, 1991.

	Corm yield (Kg plant^{-1}) ± SD	
	12 months	14 months
Exportac. Market	0.74 ± 0.27	1.10 ± 0.45
Local Market	1.09 ± 0.39	1.27 ± 0.53
Reject	0.29 ± 0.22	0.25 ± 0.22
Total Yield	2.12 ± 0.66	2.62 ± 0.96
Ton ha^{-1} [1]	35.3	43.7

[1]16666 plants

Table 4. Corm head length, diameter and weight on *in vitro* white cocoyam harvested at 12 and 14 months after planting. Quepos, 1991.

	Corm head ± SD		
Treatments	Length (cm)	Diameter (cm)	Weight (Kg)
12 months	21.77 ± 3.61	8.89 ± 1.89	1.50 ± 0.41
14 months	26.92 ± 3.85	8.17 ± 1.68	1.62 ± 0.59

[1]16666 plants

SCREENING SWEET POTATO GERMPLASM FOR HIGH DRY MATTER

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ABSTRACT

Sweet potato is an extremely valuable crop for people in tropical regions. It is a high energy food source and unlike many other root crops, is an excellent source of vitamins and minerals. Sweet potato is one of eight crops identified by National Aeronautics and Space Administration (NASA) for bioregenerative studies. One of the objectives of the sweet potato breeding program at Tuskegee University is the selection of high yielding cultivars with high dry matter content. Such cultivars can be made available to the Caribbean region as an alternate high energy crop requiring minimal inputs. To identify such cultivars, field screening of over 300 breeding lines were evaluated over a two year period. Selections made from these trials were further evaluated for their adaptability in the Tuskegee University-NFT system. A dry matter content of 25% or more was the major criterion used for selection. Initial planting sources were seeds derived from ten accessions. After the initial screening ten lines were evaluated in replicated trials in the first year. These lines were placed in advanced replicated trials in the second year for further evaluations. Results of the first year data showed dry matter content ranged from 28.8 - 40.9%, with yields ranging from 8.4-37.2 Mt/ha. In the second year, yields were higher ranging from 13.87-58.06 Mt/ha. From these evaluations all lines except K-123.20, which showed very poor yields, were recommended for testing in the TU-NFT system.

INTRODUCTION

The sweet potato is ranked fifth among all major food crops in total production and economic value (Gregory et al., 1988). In most of tropical regions it represents a significant source of energy (Bouwkamp, 1985; Wolfe, 1992). This high energy source is mainly attributed to its ability to accumulate large amounts of dry matter (Takagi and Opena, 1988).

Generally, there exists no correlation between yield and dry matter content (Kuo and Chen, 1992). However, with the sweet potato recently selected by NASA as one of several crops identified as a potential food source for long-term space missions, the dry matter content of the sweet potato is of concern in bioregenerative studies. Such concerns have resulted in the need to screen sweet potato germplasm for their dry matter content and to further evaluate these selected lines in the TU-NFT system. Germplasm identified from this study will have application not only for bioregenerative systems but will also be beneficial to the Caribbean community as an alternate high energy crop that will require minimal inputs to maintain high yields. This study was initiated to evaluate sweet potato germplasm in the field for high dry matter content and yield.

MATERIALS AND METHODS

Field evaluations were conducted over a two year period at the Tuskegee University Agricultural Experiment Station in Tuskegee, Alabama. Seeds of ten accessions resulting in 300 breeding lines were initially evaluated in the field. Eight of these lines were selected based on the dry matter content and yield were evaluated in replicated field trials. Dry matter selection criterion was based on a dry matter of 25% or higher. A complete randomized design was used with four replications.

Sweet potato vine cuttings were planted 18 cm apart on 75 m rows, 1m apart. All plots received a preplant application of 56 Kg N, 60 Kg P, and 112 Kg K/ha. Four weeks after planting ammonium

nitrate was applied at 38 Kg N/ha. Six weeks later muriate of potash was applied at the rate of 112 Kg K/ha. In both years plants were grown under rainfed conditions. Plants were harvested 120 days after planting. At harvest, roots were graded and weighed according to present USDA standards. For dry matter determination, 50g samples were taken from five randomly selected roots from US #1 grades and dried at 70C for 48 hours. Analysis of variance was conducted at the five percent probability level and, where F test warranted it, LSD was calculated.

RESULTS AND DISCUSSION

Table 1 shows the results of sweet potato yields in the first year. Total yield for all genotypes evaluated ranged from 6.4-37.2 Mt/ha with AC 87.8.16 producing the highest yield. The highest yield of jumbos were produced by AC 85.42.10, an indication that this might be an early maturing cultivar. Greatest amounts of US#1 roots were produced by AC 87.8.16 and this was significantly greater than those produced by all other genotypes except J8 17.

Dry matter content of the breeding lines showed a range of 28.8-40.9%. Highest dry matter content was obtained from J8.17. Biomass PX.2, AC 87.8.16 and AC 87.7.7 all of which were significantly higher than that of J6.5, K-123 and J6.23. K-123 contained the lowest dry matter content.

From results of the first year evaluation, all genotypes except K-123 were recommended to be tested in the TU-NFT system. Although the dry matter content for this genotype was above the 25% selection criterion, this we believe did not compensate for its low yields.

In the second year, breeding lines evaluated in advanced replicated trials showed genotypic differences in total production of storage roots (Table 2). The overall total storage root production was higher than the previous year for all lines evaluated. J6.23, an orange flesh genotype yielded the lowest amounts of storage roots with canners contributing the greatest proportion to total production. In contrast J6.5 which is also an orange-flesh genotype, produced the highest yield of storage roots with canners and US#1 grades contributing equally to total production. The remaining genotypes (white flesh roots) showed no differences in total storage root production. Generally, more jumbo roots were produced by white-flesh genotypes compared to orange flesh with the latter producing more medium size sweet potato grades. All genotypes except J6.23 produced similar amounts of US#1 roots. While genotypic differences were shown for canner roots, the opposite was shown for unmarketable roots where all genotypes produced almost equal amounts of unmarketable roots. Dry matter accumulation ranged from 18.22-35.9% and was generally lower compared to the previous year. Although J6.5 produced the greatest amounts of storage roots, its dry matter content was significantly lower than white-flesh genotypes. Overall, white-flesh roots showed higher dry matter content than orange flesh roots.

In experiment II, genotypes also showed differences in total production of storage roots (Table 2). AC 83.3.13 was the highest producer followed by J6.102. However, AC 83.3.13 produced more jumbos and unmarketable roots than J6.102. Biomass PX.30 was the lowest producer in storage roots but accumulated the largest amounts in dry matter. The two highest producing genotypes showed the least accumulated dry matter. Genotypes evaluated in the second year were also recommended for testing for adaptability in the TU-NFT system.

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Table 1. Yield of eight sweetpotato breeding lines in replicated trials.

Breeding line	Total Yield	Jumbo	US #1	Canners	Culls	% Dry Matter
			----Mt/ha--			
J6.5	18.4bc	2.1b	9.3b	4.3ab	2.7a	30.5d
J8.17	20.50abc	0b	13.5ab	4.7ab	2.3a	40.9a
J6.23	14.0bc	0.4b	8.4b	3.6b	1.6a	35.5c
AC 87.7.16	16.5bc	2.0b	8.8b	3.5b	2.2a	39.0abc
AC 85.42.10	28.9ab	13.5a	10.9b	2.2b	2.3	36.6bc
AC 87.7.7	19.9bc	1.6b	12.4b	3.8ab	2.1a	39.2ab
AC 87.8.15	13.8bc	0.5b	7.0b	3.7b	2.6a	36.5bc
AC 87.8.16	37.2a	4.9b	25.2a	4.3ab	2.7a	39.8ab
Biomass PX.2	18.3bc	0.6b	9.6b	6.5a	1.6a	39.8ab
K 123.20	6.4c	0b	1.9b	0.9b	3.6a	28.8d

Table 2. Yield of eight sweetpotato breeding lines in advanced replicated trials.

Breeding line	Total Yield	Jumbo	US #1	Canners	Culls	% Dry Matter
			Mt/ha			
J6.5	58.06c	0a	28.41b	22.32b	7.33a	21.31a
J8.17	37.96abc	1.01ab	22.00b	8.29a	5.66a	35.99b
J6.23	13.87a	0a	0a	11.83ab	2.03a	18.22a
AC 87.7.16	36.90abc	6.51b	16.23b	11.92ab	2.24a	35.98b
AC 85.42.10	32.04ab	3.72ab	20.04b	4.23a	4.06a	33.64b
AC 87.7.7	39.00bc	0a	26.29b	12.09ab	1.61a	35.98b
AC 87.8.15	46.59bc	2.62ab	25.19b	11.41ab	7.36a	34.70b
AC 87.8.16	41.00bc	0a	21.31b	14.96ab	4.73a	34.16b

Table 3. Yield of ten sweetpotato breeding lines in replicated trials.

Breeding line	Total Yield	Jumbo	US #1	Canners	Culls	% Dry Matter
			Mt/ha			
AC 83.3.8	30.10ab	0a	21.19abc	6.99a	1.92a	29.79bcd
AC 83.3.13	86.36d	12.00b	36.86abc	15.34abc	22.15b	29.24abc
Biomass PX.10	58.73abcd	0a	12.40a	44.64d	1.69a	33.59cde
Biomass PX.25	55.69abcd	0a	16.12abc	33.26cd	6.31a	31.47cd
Biomass PX.27	50.28abcd	0a	24.24abc	19.50abc	6.54a	34.91de
Biomass PX.30	27.51a	0a	14.93ab	10.89ab	2.48a	36.69e
Biomass PX.33	69.58bcd	2.54a	37.72abc	26.46abcd	7.86a	29.6bc
Biomass PX.36	41.65abc	0a	32.72abc	26.46abc	7.86a	29.6e
J6.102	75.30cd	0a	64.03c	29.76bcd	6.09a	24.24a
J8.1	55.24abcd	1.8a	28.63abc	28.63abc	8.57a	24.94ab

BIOMASS PRODUCTION AND NUTRITIVE VALUE OF LEUCAENA EDIBLE FORAGE OF DIFFERENT STEM DIAMETERS

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ABSTRACT

Dry matter (DM) production, crude protein (CP) content, *in vitro* digestibility (IVOMD), and an intake of DM, CP and metabolizable energy (ME) of leucaena forage with stem diameters up to 8, 12, 15 and >15 mm were evaluated to determine maximum twig size for inclusion in chopped leucaena for feeding goats. CP and IVOMD for 8 mm (177 and 490 g/kg DM, respectively) were about 15 per cent higher but forage DM yields (13.5 t/ha/yr) were 36 per cent lower than for the other stem sizes. Intake (per kg body weight) of DM, was similar across all stem diameters, but that of CP and ME for >15 mm (1.79 g and 70.8 kJ) was lower ($P < 0.05$) than for 8 mm (2.40 g and 102.1 kJ). However, nutrient concentration and intake remained high up to 15 mm. It was concluded that chopping leucaena forage prior to feeding will permit the inclusion of twigs 15 mm in diameter (about twice the size of an ordinary pencil) without detracting from the nutrient intake of goats, while allowing for 20-40 per cent higher stocking rates.

INTRODUCTION

Leucaena is one of the multipurpose trees now used extensively in the humid and subhumid tropics and subtropics as a source of roughage and protein supplement for ruminant livestock (Pound and Martinez Cairo 1983; Proverbs 1985). It is used principally in grazing and cut and carry production systems, but in either case the edible portion is limited to the leaves and the green soft stems up to 5-6 mm in diameter (Guevarra 1978; Hulman *et al.* 1978; Ferraris 1979; Kitamura 1985; Cooksley *et al.* 1991).

There is very little information on the feeding and utilization by small ruminants of leucaena forage with stems bigger than 5-6 mm. Quintyne *et al.* (1987) fed Barbados Blackbelly sheep leucaena silage (plus cassava silage) made from whole leucaena about 1 m high and with about 42% stem in the dry matter, and recorded live weight gain of 115.7 g/day. Sheep and goats, however, differ in their ability to consume and use leucaena forage. Goats tend to have higher dry matter intake, are better able to digest and retain more nitrogen from leucaena forage than sheep (Devendra 1982; Yates 1982). Thus it appears goats can probably derive more benefit from a greater portion of leucaena forage than what has previously been classified as edible forage.

This study was therefore undertaken to determine the dry matter production and nutritive value for goats of leucaena edible forage including stems of different diameters.

MATERIALS AND METHODS

Site

The study was conducted at the Hounslow Sheep and Goat Center in the parish of St. Elizabeth, Jamaica (18°2'N, 77°37'W, 1205 mm annual rainfall, bimodal distribution in May/June and September/November, and 28.9°C daily temperature). The soil at the site is St. Ann Clay Loam (Stark 1963) with pH 6.4.

Treatments and forage sampling

In November 1990 seeds of leucaena (var Cunningham) were sown, after hot water scarification, on a 2 x 1 m grid on a 0.5 ha land. The seeds were not inoculated and no fertilizer or lime was applied at establishment. A clearing cut was made 9 months after establishment. Subsequently the field was divided into 6 sections of about 800 m^2 and allotted randomly to 6 treatments.

The 6 treatments called categories of edible forage and defined by the maximum stem diameter were: 6, 8, 10, 12, 15 and >15 mm. Three random samples each 9 m^2 were taken from each treatment section after 12 weeks regrowth during the first cutting year. After weighing the total harvested forage three sub-samples of about 1 kg each was taken for each treatment. One sub-sample was weighed and dried in a forced draft oven for the determination of total biomass dry matter yields. The other two sub-samples were separated into edible and non-edible parts. One of the two edible parts sub-samples were weighed and dried for the determination of total edible forage yields, while the other was separated into leaf and stem fractions.

Chemical analyses

The dried total edible forage, and the leaf and stem fractions were ground through a 1 mm screen and analyzed for crude protein concentration (Nitrogen x 6.25) and *in vitro* organic matter digestibility. Metabolizable energies were calculated from equations relating crude protein and gross energy, and gross energy and digestible /metabolizable energy (Xandé *et al.* 1989).

Intake

In a 23-day feeding trial edible forage from the 6 treatments was chopped using a motorized forage chopper and fed to three classes of three goats each in two replicates. The classes of goats were adult Anglo-Nubian x Native (AN x N)(body weight 41.8±1.21 kg), young AN x N (24.2±3.68 kg) and young Anglo-Nubian (24.1±2.45 kg). The goats were offered the leucaena at the rate of 15 g/kg body weight dry matter and king grass *(Pennisetum typhoides* x *P. purpureum) ad libitum.* The leucaena was fed continuously for 21 days and intake was measured on the next two consecutive days.

Statistical analyses

The data were first analyzed using GENSTAT 5 statistical packages (Lawes Agricultural Trust 1990) and the means tested by pair wise multiple comparisons. These initial analyses showed no significant differences ($P>0.05$) between the 6 and 8 mm, and between the 10 and 12 mm treatments. The data for each of the two pairs of treatments were therefore pooled, and the mean for up to 8 mm compared with those for 12, 15 and >15 mm using Bonferroni t-test for post data contrasts (Gill 1978).

RESULTS AND DISCUSSION

The yield of edible forage with stems 12 mm and above was on average 36% higher ($P<0.01$) than that for 8 mm stems (Table 1). Associated with this increased yield was a corresponding significant increase ($P<0.01$) in the percentage edible forage in the total biomass, and of the stem fraction. The leaf fraction of the edible forage was, however, inversely related ($P<0.01$) with the increased stem diameter.

The crude protein (CP) concentration and organic matter digestibility (IVOMD) of the edible forage with stem diameter >15 mm declined by 18% and 22% ($P<0.01$) respectively compared with the values for the 8 mm edible forage (Table 2). The levels of decline for the 15 mm stems (10% for

CP and 11% for IVOMD) were just about one-half those for >15 mm stems. The decline of nutrient concentration in the stem fraction followed similar trends as for the total edible forage, but there were no apparent changes in the leaf fraction nutrient concentration (Table 2).

The yield of leucaena edible forage with stems up to 8 mm in diameter was consistent with that of Cunningham and other Peru type leucaena in the Caribbean (Pound and Martinez Cairo 1983; Proverbs 1985) and in Australia (Hutton and Beattie 1976; Ferraris 1979). Likewise the CP concentration and the IVOMD were comparable with those obtained elsewhere (Hulman *et al.* 1978; Brewbaker and Hutton 1979).

The decline in CP concentration and IVOMD in the total edible forage was attributed primarily to the decline of the concentration of these nutrients in the stem since there were no significant changes in the nutrient concentration of the leaf fraction (Table 2).

Forage intake was on average 13.1 g/kg body weight (86.1% of forage dry matter offered) and there was no significant difference (P>0.05) between 8 mm stem and the bigger stems (Table 3). This high percentage voluntary consumption even with chopped bigger stems in the forage corroborates the knowledge (Pound and Martinez Cairo 1983) on leucaena palatability. On the other hand the intake of CP and metabolizable energy (ME) declined by 25% and 31% respectively for >15 mm stems, and by 13% and 15% respectively for 15 mm stems.

There were no effects of breed or age of goats on the intake of forage or intake of nutrients. The range of intake values across the three classes of goats was: dry matter (g/kg body weight), 12.4-13.5, dry matter (% dry matter offered), 82.0-88.8, CP (g/kg body weight), 2.01-2.16 and ME (kJ/kg body weight), 83.6-92.8.

The literature on leucaena edible forage with stems >5-6 mm in diameter is scanty, but there are indications that the forage yield, stem fraction and CP concentrations recorded for stem diameters 12 mm and above in this study agree with the findings for Cunningham variety in the literature. Ferraris (1979) reported that the yield of total leucaena cut to 5-15 cm above ground level and at 2-4 months interval was 21.8 t/ha/yr, with 53% stem in the dry matter. The corresponding CP values were 15.6% and 6.3% respectively. Quintyne *et al.* (1987) also recorded 42% stem fraction in the forage of whole leucaena.

The general trends demonstrated in the present work were that with the inclusion of stems >8 mm in leucaena edible forage yields was maximized and there were increased fractions of leucaena forage offered, of which more than 80% was consumed by both young and adult goats.

Notwithstanding the consumption of a high proportion of the forage, the intake of CP and ME was compromised with the inclusion of stem >15 mm. On the contrary the dilution of nutrient concentration with the inclusion of stems up to 15 mm in diameter was not dramatic; the CP concentration was even well maintained (160 g/kg dry matter) up to this point (Table 2). Also it can be determined from the data on forage yield and forage offered that by including stems 12-15 mm in diameter as part of the edible forage 20-40% more adult goats (45 kg body weight)per annum can be accommodated on a unit leucaena pasture compared with edible forage with stems only up to 8 mm (calculated stocking rate = 54 goats/ha/yr).

The conclusion from the study is that where a forage chopper is available the edible forage of leucaena fed to goats may include stems up to 15 mm in diameter (about twice the size of an ordinary pencil) without detracting from the nutrient intake and at the same time increasing the stocking rate.

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Table 1. Effect of stem diameter on dry matter (DM) yield, and proportion of leaves and stem in leucaena edible forage.

Parameter	Stem diameter (mm)				SE[1]
	8	12	15	>15	
Edible forage DM yield (t/ha/yr)	13.5	16.2	18.5	20.4	2.40
Edible forage in total biomass DM (%)	71.8	84.2	89.9	100.0	5.53
Leaves in edible forage DM (%)	67.0	59.3	55.6	44.8	3.00
Stem in edible forage DM (%)	33.0	40.7	44.4	55.2	2.96

[1] SE = Standard error for comparing 8 mm vs 12, 15, >15 mm (error degrees of freedom = 30, number of contrasts = 4).

Table 2. Effect of stem diameter on crude protein concentration and *in vitro* digestibility (IVOMD) of total forage and of leaf and stem fractions of leucaena edible forage.

Parameter	Stem diameter (mm)				SE[1]
	8	12	15	>15	
Crude protein (g/kg DM[2])					
Total forage	177	162	160	145	5.7
Leaves	224	238	241	241	17.2
Stem	86	64	62	60	8.6
IVOMD (g/kg DM)					
Total forage	490	453	435	381	20.9
Leaves	607	615	609	630	27.7
Stem	256	216	206	184	13.2

[1] SE = Standard error for comparing 8 mm vs 12, 15, >15 mm (error degrees of freedom = 30, number of contrasts = 4).

[2] DM = Dry matter.

Table 3. Effect of stem diameter of leucaena edible forage on intake of dry matter (DM), crude protein (CP) and metabolizable energy (ME).

Parameter	Stem diameter (mm)				SE[1]
	8	12	15	>15	
DM intake (g/kg body weight)	13.3	13.0	12.9	12.6	2.99
DM intake (% DM offered)	90.0	87.0	84.1	83.4	10.47
CP intake (g/kg body weight)	2.40	2.12	2.08	1.79	0.205
ME intake (kJ[2]/kg body weight)	102.1	90.6	86.8	70.8	10.44

[1] SE = Standard error for comparing 8 mm vs 12, 15, >15 mm (error degrees of freedom = 14; number of contrasts = 4).
[2] kJ = kilo joule.

EFFECT OF DAYLENGTH ON THE DEVELOPMENT OF INTERSPECIFIC *PENNISETUM* HYBRIDS

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ABSTRACT

Pearl millet (*Pennisetum glaucum* L. Leeke) x napiergrass (*P. purpureum* Schum.) interspecific hybrids (PMN) have great potential as a forage crop in the tropics. The effect of daylength on the flowering of cytoplasmic-nuclear male sterile (cms) pearl millet Tifton $23A_4$, and three napiergrasses (N14, N20, and N74) was determined in monthly plantings for a period of one year. Fifty days after planting, the male parents (napiergrass) were cut to the ground level (T1), to one meter above-ground (T2), or not cut (T3). Days from planting to flowering (PF) for pearl millet ranged from 44 to 47 across plantings and 50 or less for N14 and N74 (from August to December). Although flowering of the male parents was not influenced by the T2 and T3 treatments, the T1 treatment caused plants to flower later. With the exception of the T1 treatment, flower response to daylength was as expected. Seed of the PMN can be obtained from August through December in Puerto Rico but not during long days of (12 hours of daylight or more) unless day-neutral male parents are used.

INTRODUCTION

Hybrids between pearl millet (*Pennisetum glaucum*) and napiergrass (*Pennisetum purpureum*) have great potential for livestock production and as a biomass energy crop (2,6,7,8). Some reports (3,4) have suggested a method of producing triploid seed of the hybrid, but the proposed scheme has never been adopted by the seed industry. In Hawaii, Osgood et al. (3) demonstrated a potential method of commercial production of the PMN based on the use of cytoplasmic-nuclear male-sterile (cms) pearl millet as the female parent and napiergrass as the pollen parent. These authors tested several treatments to determine the best regime to maximize pollen production at the time of pearl millet anthesis. The most successful nick occurred when the napiergrass was cut four feet above ground on September 25th. At that time, acceptable PMN seed production was obtained. The objective of this study was to evaluate the effect of daylength on the flowering response of cms pearl millet and three napiergrass selections when planted monthly during one year in Puerto Rico.

MATERIALS AND METHODS

The experiment was conducted at the Isabela ARS experiment farm, 128 m elevation with ambient temperatures ranging from 18.5 to 29.4° C. The soil was an Oxisol (Typic Hapludox) with an organic matter content of 2.5% and pH of 5.0. The experimental design was a randomized complete block arranged in a split-split plot with two replications.

Planting dates (PD) were the main plots (made the 4th day of each month from December, 1992, (planting date 1), to November, 1993), (planting date 12); the grasses, the subplots (N14, N20, N74 and Tifton $23A_4$); and cutting treatments the sub-subplots (T1 (ground level), T2 (one m above ground), and T3 (not cut)). The three napiergrasses and cms pearl millet Tifton $23A_4$ were supplied by Wayne W. Hanna, USDA-ARS, Tifton, Georgia.

Twenty four basal clones from each male parent, 25 cm long with at least three nodes were placed in 20 cm pots and covered with a plastic bag during a two-week period prior to planting, which permitted the induction of adventitious roots. Seeds of the cms pearl millet ($23A_4$) were hand

drilled 0.5 m apart west of the male parents on the 23rd day of each month from January to December, 1993. The three cutting treatments were initiated 50 days after the male parents were planted (simultaneously with female planting). Weeds were controlled by hand-weeding. Overhead irrigation was applied to all plots as needed.

Days from planting to flowering (PF) were recorded when 50% of plants in the plot had reached anthesis. Percentage of seed set and quality of seed produced were determined for the PMN, and plant height (taken at 120 days for PMN and at 150 for check male parents) for all parents.

RESULTS AND DISCUSSION

In Puerto Rico's latitude (18°N), daylength ranges from 11.02 (December 20-22) to 13.13 hours (June 20-21), a factor which is determinant in the flowering response of photoperiod sensitive plants (Table 1). Reports indicate (1,8) that napiergrasses are photoperiod sensitive, flowering only under short-day periods. On the other hand, cms pearl millet is a day-neutral plant, flowering profusely throughout the year in the tropics. According to Hanna (personal communication), under the Tifton, Georgia, growing conditions of 11 hours or less, $23A_4$ PF ranges from 55-60. At daylength of over 11 hours, PF ranges from 75-80.

In this experiment, PF of $23A_4$ was very similar throughout the year. Under the Isabela, Puerto Rico, conditions it ranged from 44 (March planting) to 47 days (July planting). Apparently, the critical photoperiod of $23A_4$ is above 13.13 hours. Mean plant height of $23A_4$ ranged from 1.0 (December planting) to 1.4 m (April to July plantings). In general, $23A_4$ plant height averaged 1.0 m when it was planted during short days and 1.4 m when planted under long days of 12 hours or more (Table 2). Seed set on $23A_4$ ranged from 10% (August planting) to 60% (September to November plantings). Although seed set in the December, January, and February plantings was less than 60%, seed quality was superior (Table 2).

For any of the treatments to be effective, the napiergrass male parents must flower about the same time as the female plants or in about 46 days. The PF of N14 was delayed for more than five months when it was planted from December to June (T1 cutting treatment), from January to June (T2), and from January to May (T3). Our results indicate that PF of N14 decreased from 160 to 120, 105 to 90, and 120 to 35 days when it was planted from July to October, July to November, and June to December under T1, T2, and T3 cutting treatments, respectively (Table 3). When N20 was cut under T1 treatment, it took over 160 days to flower throughout the year. This was also true when it was planted from December to June under T2 and T3 treatments. The PF of N20 decreased from 110 to 100 (July to October plantings) and from 100 to 45 days (July to November plantings) when it was cut under T2 and T3 treatments, respectively. For N74, PF increased to over five months when it was planted from December to June, January to June, and February to May under T1, T2, and T3 cutting treatments, respectively. On the other hand, the PF of N74 decreased from 150 to 110 and 95 to 80 days when it was planted from July to October under T1 and T2 treatments, respectively. The greatest decrease in PF of N74 occurred between June and the December plantings (115 to 35 days), but there was a sharp increase in PF to 100 days for the January planting.

Floral initiation of N14 and N74 under T3 ranged from 50 to 35 days (September to December plantings) during short days, and these grasses can be regarded as potential pollen parents for the development of PMN. Daylength of over 12 hours had the greatest effect on N20, while a smaller effect was observed on N14 and N74.

This study demonstrated that a cutting treatment on male parents is not required to synchronize flowering for the female and male parents. From the data obtained, it can be concluded that a proper flowering synchronization is possible if pearl millet is planted simultaneously with N14 and N74 from August to December and with N20 from October to November.

Plant height (taken at 150 days period) of N14, N20 and N74 (Table 4) increased, respectively; from 2.3, 1.9 and 2.3 meters (December planting) to 3.1, 2.6 and 3.0 meters (July planting);

then decreased to 2.3, 1.9 and 2.3 meters (November planting). Plant height of the three napiergrasses was higher when they were planted during longer days (more than 12 hours of daylight).

This study demonstrates the need of utilizing day-neutral male parents if seed of the PMN is to be produced throughout the year in Puerto Rico. High quantity of high quality seed can be produced when genotypes similar to those used in this study are planted from November to January.

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Table 1. Mean daylength for the 1st, 15th, and last day of each month and monthly average daylength in Puerto Rico.

Month	Day 1st	15	20	21*	Last	Mean daylength
			hours			
January	11.04	11.10			11.21	11.11
February	11.22	11.34			11.47	11.30
March	11.47	12.02			12.18	11.86
April	12.20	12.34			12.47	12.32
May	12.48	12.59			13.09	12.59
June	13.09	13.12	13.13 (longest)		13.12	13.12
July	13.12	13.07			12.57	13.07
August	12.56	12.45			12.30	12.43
September	12.29	12.14			12.00	12.14
October	11.59	11.44			11.30	11.44
November	11.29	11.17			11.08	11.17
December	11.08	11.03	11.02 (shortest)		11.04	11.04

* Longest days (June 20-21) 13.13 hours; shortest days (December 20-22) 11.02 hours; 12-hour days occur March 13 and September 29.

Table 2. Days to midflower, plant height, grain quality and % seed set of Tift $23A_4$ when planted monthly during a period of one year at Isabela, P. R.

Planting Date[1/]	Days to Midflower	Plant height (m)	Grain quality[2/]1	% Seed set
January	46	1.1	1	40
February	47	1.3	2	15
March	44	1.3	-	0
April	46	1.4	-	0
May	45	1.4	-	0
June	45	1.4	-	0
July	47	1.4	-	0
August	45	1.3	3	10
September	46	1.3	3	60
October	47	1.3	3	60
November	45	1.1	3	60
December	46	1.0	2	50

[1/] Planted the 23rd day of each month.
[2/] 1 = good; 2 = intermediate; 3 = poor.

Table 3. Response of three napiergrass selections[1/] to three defoliation treatments[2/] when planted monthly during the period of one year at Isabela, P. R.

Napiers	N14			N20			N74		
Planting dates	T1	T2	T3	T1	T2	T3	T1	T2	T3
	-- DAYS TO ANTHESIS --								
December	---	120	35	---	---	---	---	110	35
January	---	---	---	---	---	---	---	---	100
February	---	---	---	---	---	---	---	---	---
March	---	---	---	---	---	---	---	---	---
April	---	---	---	---	---	---	---	---	---
May	---	---	---	---	---	---	---	---	---
June	---	---	120	---	---	---	---	---	115
July	160	105	100	---	110	100	150	95	95
August	150	100	66	---	100	70	140	90	45
September	125	100	50	---	100	70	120	80	45
October	120	90	45	---	100	45	110	80	40
November	130	90	40	---	110	45	130	90	40

[1/] N14, N20, N40

[2/] T1 = cut close to ground 50 days after planting.
T2 = cut at one meter above ground 50 days after planting.
T3 = no cut.

Table 4. Effect of daylength on plant height (m) of three napiers selection when planted monthly at Isabela, P.R.

Planting date	Napiers N14	N20	N74
December	2.3	1.9	2.4
January	2.5	2.0	2.5
February	2.7	2.2	2.7
March	2.8	2.4	2.8
April	3.0	2.5	3.0
May	3.1	2.5	3.0
June	3.1	2.5	3.0
July	3.1	2.6	3.0
August	3.1	2.4	2.8
September	2.8	2.3	2.8
October	2.6	2.0	2.4
November	2.3	1.9	2.3

FORAGE YIELD, QUALITY AND PERSISTENCE OF INTERSPECIFIC *PENNISETUM* HYBRIDS IN THE CARIBBEAN

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ABSTRACT

The species *Pennisetum purpureum* includes perennial, high yielding and good quality forage types. However, the need for vegetative propagation has limited its commercial use. In two 2-year experiments, forage yield and quality, and stand persistence of 'Mott' dwarf elephantgrass (*P. purpureum*) were compared with either those of other pure lines of elephantgrass (N43, N114, N127 and N128) or their interspecific hybrids with pearlmillet (*P. glaucum*) grown in mixture with glycine (*Neonotonia wightii*). Grasses were harvested every 60 to 100 days, based on rainfall. In neither year was there a genotype x harvest date interaction for dry matter yield. Annual forage yield of tall pure lines or their triploid hybrid with pearl millet was 21-29 t/ha compared with 9-23 t/ha from Mott and its seeded hexaploid derivatives. Forage in vitro organic matter digestion (IVOMD) for Mott (65%) at 60-day regrowth was similar to the hexaploids, but superior to the tall lines (60%). Minimum crude protein (CP) content and IVOMD of *Pennisetum* forage stockpiled for 90 days were 7% and 54% for dwarf types and 6% and 54%,for tall types, respectively. Mott cultivar maintained higher plant and tiller numbers than the hybrids. Legume content of dry forage at the final harvest was 40-48% for the hybrids and 28% for Mott. Seed propagated *Pennisetum* hybrids have a potential for stockpiled forage in the Caribbean if their persistence is improved.

INTRODUCTION

The livestock industry in the Caribbean Basin is based on grazing native pastures. Forage quantity and, particularly, forage quality become serious obstacles to livestock productivity in the dry season. *Pennisetum* is a very diverse genus and the species *P. purpureum* is one of the highest dry matter producing grasses in the tropics (Vincente-Chandler et al. 1959, 1974, Velez-Santiago and Arroyo-Aguilu 1981, Wan Hassan et al. 1990). Mott, a very digestible dwarf elephantgrass (Mott and Ocumpaugh 1984), has produced average cattle daily gains of 0.97 kg (Sollenberger et al. 1988) which is unusually high for a tropical grass. However, all pure selections or varieties of elephantgrass have very low natural seed production with low seed viability and have to be vegetatively propagated. The high labour requirement and cost of establishment have limited the adoption of elephantgrass as a forage crop.

Pearlmillet hybridizes readily with elephantgrass and some hybrids have been released in India (Krishnaswamy and Raman 1954), parts of Africa (Aken'ova and Chheda 1981) and other tropical countries (Muldoon and Pearson, 1979). The F_1 hybrids between pearlmillet (diploid) and elephantgrass (tetraploid) are triploids which are completely sterile due to unbalanced chromosome distribution during meiosis (Khan and Rahman 1963, Hanna 1981, Schank et al. 1989). Hence, the triploids must be multiplied vegetatively unless there is a specialized production and supply of

certified seed. However, when the chromosome number of the triploid is doubled to form a hexaploid, either by using colchicine (Hanna 1981, Hanna et al. 1984) or tissue culture (Rajasekaran et al. 1986, Diz and Schank 1991), fertility is restored and large viable seed can be produced. Rapid progress is being made in obtaining seeded-type pearlmillet-elephantgrass hybrids that are similar in yield and quality performance to pure elephantgrass (Schank et al. 1993, Schank et al. 1989, Boddorff and Ocumpaugh 1986, Hanna and Monson 1980), and there is considerable interest in the tropics in this development.

The objective of this study was to compare, in the Caribbean environment, yield and quality performance of selected genotypes of *Pennisetum* at three ploidy levels.

MATERIALS AND METHODS

Two separate trials were conducted at the University of the Virgin Islands' Agricultural Experiment Station, on St. Croix (Latitude 17° 43' N, and Longitude 64° 48 ' W). The soil was a mildly alkaline (pH 7.8) Fredensborg clay (Fine carbonatic, isohyperthermic, Typic Rendolls Mollisols) . Mean monthly temperatures range from 24 to 27 °C. Annual rainfall averages between 1000 mm with 50 % of rain falling during the months of September to December. Open pan evapotranspiration exceeds 1800 mm per year.

Experiment 1

Germplasm for this trial included five tetraploid elephantgrass lines — N43, N114, N127, N128 and cv. Mott. Varieties N43 and N114 were tall types whereas the remaining were dwarf types (Figure 1). Stem cuttings with three nodes (N43 and N114) and cuttings approximately 0.4 m in length which included four to five nodes (N127, N128 and Mott) were planted 0.625 m apart in rows 6.25 m long in July, 1990. Rows were spaced 1.25 m apart and each row represented a plot. Depending on the quantity of planting material received, between two and four replications of each line were established under rainfed conditions, in a randomized block design. Established plots were cut back to a 15-cm stubble in mid December, 1990. Plots were given 75 kg/ha of N , yearly, in two split applications. Beginning from late February, 1991, varieties were repeatedly harvested every 60 to 100 days, based on amount of rainfall (Table 1), through January, 1993. Prior to each harvest, height measurements were taken of three randomly selected plants in a plot and averaged. Subsamples of harvested forage were dried at 60 °C to constant weight and ground to a 1 mm size. Dried subsamples of selected harvests (60 and 90 day regrowth) were analyzed for CP (Gallaher et al., 1975) and IVOMD (Moore and Mott, 1974).

Experiment 2

Germplasm for this study consisted of four seed producing hexaploids (2n=42) HX2, HX3, HD105, HD237 developed by Dr. S. C. Schank, University of Florida, Gainesville; a tall triploid (2n=21) selection (MEF1) which was a cross between tall pearl millet (*P. glaucum*) (2n=14) (Tift 23A) and three tall *P. purpureum* (2n=28) lines (N14, N23. N74), developed by Dr. W. W. Hanna, USDA-ARS, Tifton Georgia; and a dwarf tetraploid (2n=28), Mott elephantgrass.

The procedure for the development of the hexaploids is well documented (Diz and Schank 1991). Briefly, the cytoplasmic male-sterile inbred 'Tift 23DA' (dwarf) pearlmillet was crossed to 'Mott' and triploid offsprings were obtained. Selected hybrids were subjected to tissue culture (Rajasekaran et al. 1986) to obtain two hexaploid plants, one of which was designated P3. The hexaploid P3 was then crossed back to two different tall hexaploid phenotypes, namely MN3 and MN33, which were developed by Dr. W. W. Hanna, in order to improve male fertility in the progeny. Mass selection for two years resulted in a population from which entries for this study were selected. At the tetraploid

level, hexaploid cross number 2 (HX2) originated from a cross of MN33 x 434 {P3 x MN3}, and the hexaploid cross number 3 (HX3) came from a different cross MN33 x 493 {P3 x MN3}. HD105 and HD237 are different composite seed samples from mass selection within the crosses. The hexaploid entries were therefore very heterozygous in genotype.

The study, a randomized complete block design with four replicates, was planted during the rainy season of September, 1991. Based on an initial observation of a possible shading effect of tall genotypes on dwarf types in Experiment 1, hybrids were seeded in rows 2 m apart instead of the previous 1.25 m row spacing. Four grams of seed were planted per 6.25 m row (3.2 kg/ha). Seedlings were thinned to 0.625 m intra-row spacing when they were approximately 15 cm in height. Mott was vegetatively propagated as described in Experiment 1 with a 0.625 m intra-row and 2 m inter-row spacing. Planted rows were side-dressed with 40-10-20 kg/ha of N-P_2O_5-K_2O to promote establishment. Alleys between rows were rototilled as needed and 2,4-D herbicide was broadcast over rows at 2.37 L/ha, using a backpack sprayer, to control weeds during the seedling stage. From January, 1992 through December, 1993, established plots were repeatedly harvested every 60 to 100 days for forage. There were four harvests each in 1992 and 1993. Heights were measured for three randomly selected plants in a row prior to each harvest. Harvested subsamples were dried and analyzed as described in experiment 1. A total of 75 kg/ha of N was applied in 1992. However, following the second (April) harvest in 1992, the 2-m alleys between rows were tilled and interseeded with three rows each of glycine (*Neonotonia wightii*) at a seeding rate of 6 kg/ha. Glycine seed was scarified in 80 °C water for 3 minutes before planting to improve germination and establishment. Nitrogen fertilizer was withheld from the study in 1993 and harvested forage for that year included legume biomass. However, component grass/legume biomass was separated only at the final (eighth) harvest. Twenty eight days after the fourth and eighth harvests, *Pennisetum* clumps in a row that had initiated regrowth were counted as live plants. Tiller numbers in 2-m section of each grass row were also counted at the same time to monitor persistence. Data on yield, quality and persistence were statistically analyzed using the GLM procedure for SAS system (SAS Institute Inc. 1988). Mean separation was performed using the Duncan's Multiple Range Test.

RESULTS

Mean plant heights ranged from 0.89 m for N128 to 1.8 m for N114 (Figure 1). Heights were affected by harvest date ($P<0.001$) and genotype ($P<0.0001$). A greater standard deviation in height was obtained for hybrids than for pure lines (Figure 1) as a result of the heterogenous genotype of the hybrids.

Experiment 1

Forage dry matter harvested of the tetraploid *Pennisetums* ranged from 18 to 21 t/ha in 1991 and 6 to 29 t/ha in 1992 (Table 2). Yield was generally higher for the tall lines (N114 and N43) than for the dwarf types. The extremely low yields for Mott and N127 in 1992 was partly due to shading effects from the well established, adjacent tall lines. This resulted in a significant year x variety interaction on yield ($P<0.05$). Variety N127 was the line with the lowest yield in both years.

With the exception of the tall genotype, N43, the nutritive value of tetraploid *Pennisetums* was not different from each other. However, there was a tendency for Mott elephantgrass to have the highest CP and IVOMD concentrations (Table 3). Crude protein content and IVOMD of N43 for the 60-day regrowth were lower than those for Mott. This was due to the earlier development of more stem material in N43.

Experiment 2

Forage yield of *Pennisetums* in the second experiment ranged between 17 and 27 t/ha/yr over the

2-year period (Table 4) and there were no genotype x harvest date (P>0.91) or genotype x year (P>0.75) interactions. The tall triploid hybrid (MEF1) was the highest yielding cultivar each year, although its yield was not significantly different from Mott. The yields of the hexaploids tested were similar to the yield of Mott. At the end of the initial year of harvest (fourth harvest), plant numbers within rows were similar for the various entries with the exception of HD237 which had a higher number of plants (Table 5). Although shorter (Figure 1), Mott elephantgrass produced more tillers and maintained a higher plant population, (Table 5) to sustain over 22 t/ha DM production, yearly, in Experiment 2. Also, as a result of Mott's vigour, legume competition was significantly reduced. Thus, legume DM in harvested forage increased to only 28% in plots planted to Mott compared to over 40% in plots planted to the seeded hybrids (Table 5). This indicates that Mott was more productive than the other seeded elephantgrasses in the second year although component grass/legume forage was not measured throughout 1993.

When compared to the hexaploid hybrids, the nutritive value of Mott was always the highest, however, CP and IVOMD of Mott was not significantly different from the hexaploids (Table 6). Averaged over Mott and the hexaploid genotypes, CP and IVOMD values were 14.84% and 62.71% for 60-day regrowth and 12.31% and 54.54% for 90-day regrowth (Table 6). The nutritive value of the tall stemmy triploid hybrid (MEF1) was much lower than Mott. Comparative CP and IVOMD values at 60 days of regrowth for the MEF1 were 13.33% and 60.98% and at 90 days, 9.31% and 52.38%, respectively (Table 6).

DISCUSSION

Forage yields of elephantgrasses obtained on St. Croix in this study agree with data reported by Vincente-Chandler et al. (1974) on Puerto Rico, which has a similar tropical climate. Except in cases where yields were suppressed by shading, our yields were higher than those reported for elephantgrass forage crops in Florida (Sollenberger et al. 1988, Chaparro and Sollenberger 1991) probably because of the longer, frost-free growing season in the Caribbean. Besides being productive, the elephantgrasses generally exhibited outstanding forage quality as previously reported (Sollenberger et al. 1988) and maintained good quality even when stockpiled over the 90-day interval. The quality superiority of Mott and its semi-dwarf hexaploid derivatives over tall genotypes has been attributed to the maintenance of a much higher leaf/stem ratio over a wide range of maturities for the dwarf types (Schank and Dunavin 1988, Boddorff and Ocumpaugh 1986). Elephantgrasses provided trellis for the legume glycine to climb. This association with a native legume if maintained in the proper balance would further improve the CP value of an elephantgrass forage bank for dry season feeding as observed in Experiment 2. Whereas the stand of Mott was uniform and proliferated with many tillers, those of the hybrids consisted of heterogeneous plants with some dieback. Thus, legume competition was kept in check by cv. Mott, whereas legume content within the hexaploids increased over time probably due to the loss in their stand and reduced tiller numbers.

CONCLUSIONS

The forage production potential of *Pennisetum* tetraploids, their triploid and seeded hexaploid derivatives with pearl millet (diploid) were compared to Mott (tetraploid) dwarf elephantgrass. The tall tetraploids out-yielded Mott in forage production but tended to be inferior in nutritive value. Forage yield of the triploid and hexaploids was similar to Mott in the first year but lower in the subsequent year due to legume competition and loss of grass stand. Nutritive value of the tall triploid was also lower than Mott. The hexaploids were not different from Mott in CP and IVOMD. Despite the advantage of being propagated from seed, we cannot at this stage recommend the hexaploids over Mott in the Caribbean until their persistence is improved through on-going recurrent restricted phenotypic selection.

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Table 1. Monthly and yearly rainfall at the experimental site on St. Croix for 1991 - 1993.

Month	1991	1992	1993
		mm	
January	35	54	50
February	66	24	43
March	45	72	33
April	26	65	86
May	44	273	180
June	28	27	67
July	77	61	151
August	36	58	51
September	52	127	90
October	87	157	59
November	80	259	182
December	39	106	61
Total	615	1283	1053

Table 2. Dry matter yield of tetraploid elephantgrasses on St. Croix.

Pennisetum variety	DM Yield		
	1991	1992	2 yr. avg.
		t/ha	
Mott	18.2b*	9.0b	13.6
N127	15.0c	6.0c	10.5
N128	16.9bc	12.6b	14.8
N114	21.4a	10.6b	16.0
N43	19.9ab	29.1a	24.5

*Values for each year not followed by the same letter are significantly different at P=0.05. Year x variety interaction was significant (P<0.05).

Table 3. Crude protein content and in vitro organic matter digestion (IVOMD) of tetraploid *Pennisetum*) forage for a sixty- and a ninety-day regrowth.

Pennisetum variety	Crude protein		IVOMD	
	60 d	90 d	60 d	90 d
	%			
Mott	8.73a*	6.85a	63.10a	57.70ab
N127	7.34ab	7.02a	60.02b	54.60b
N128	7.35ab	7.68a	59.90b	60.60a
N43	6.05b	7.82a	58.70b	60.00a
N114	8.17a	6.59a	61.19ab	54.40b

*Values for each column not followed by the same letter are significantly different at P=0.05.

Table 4. Dry matter yield of seeded interspecific *Pennisetum* hybrids and cv. Mott on St. Croix.

Pennisetum variety	DM yield		
	1992	1993[1]	2 yr. avg.
	t/ha		
Mott	22.9	22.7	22.8ab*
HX2	19.0	17.4	18.2b
HX3	18.0	20.9	19.5b
HD105	18.5	22.6	20.6b
HD237	18.1	22.8	20.5b
MEF1	27.3	25.9	26.6a

*Values for the 2-year average not followed by the same letter are significantly different at P=0.05.
[1]The 1993 yields include legume DM.

Table 5. Plant and tiller numbers of seeded interspecific *Pennisetum* hybrids and cv. Mott following the fourth and eighth repeated harvests; and legume content of dry forage at the final harvest on St. Croix.

Pennisetum variety	Number of plants		Number of tillers		Legume content
	Sept '92	Nov '93	Sept '92	Nov '93	
	#/m				%
Mott	1.60b*	2.05a	138.8a	115.3a	28.3a
HX2	1.85b	1.03b	134.5ab	50.0b	48.3b
HX3	1.75b	1.32b	105.8bc	57.7b	42.7b
HD105	2.33a	1.24b	110.8abc	38.8b	45.6b
HD237	2.1ab	1.28b	110.3abc	52.5b	42.5b
MEF1	1.63b	1.11b	95.3c	55.2b	41.0b

*Values in each column not followed by the same letter are significantly different at P=0.05.

Table 6. Crude protein content and in vitro organic matter digestion (IVOMD) of interspecific *Pennisetum* hybrids and cv. Mott for a sixty- and a ninety-day regrowth.

Pennisetum variety	Crude protein		IVOMD	
	60 d	90 d	60 d	90 d
	%			
Mott	15.40a*	13.06a	64.51a	56.40ab
HX2	14.89a	12.63ab	61.68ab	53.10a
HX3	14.56a	12.55ab	62.28ab	52.85a
HD105	14.97a	11.79b	62.15ab	55.75a
HD237	14.36ab	11.52b	62.91ab	54.58a
MEF1	13.33b	9.31c	60.08b	52.38a

*Values for each column not followed by the same letter are significantly different at P=0.05.

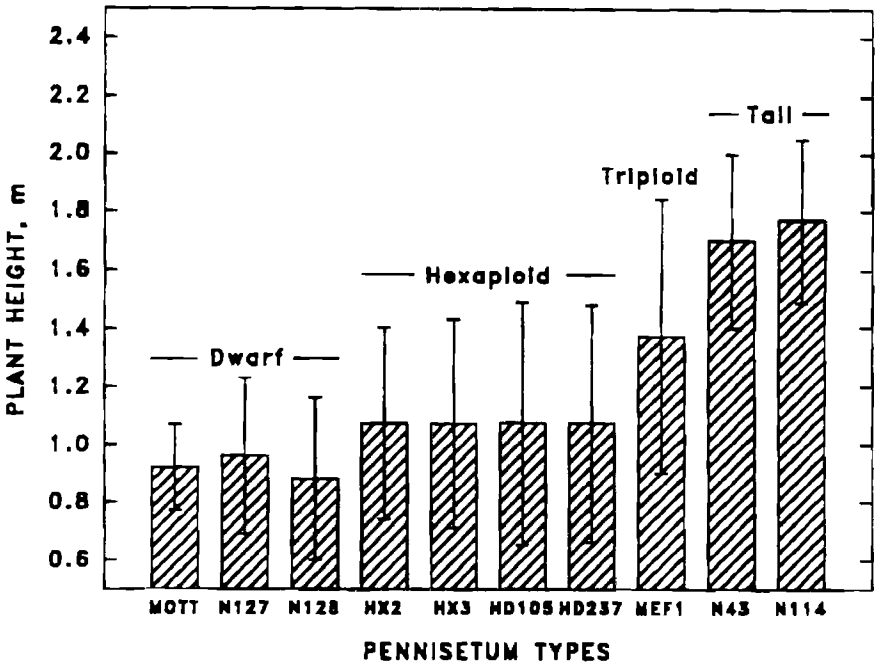

Figure 1. Average plant height of *Pennisetum* genotypesmeasured at harvest (1991-1993) on Croix.

GROWTH RESPONSE OF HAIR SHEEP FED UREA-AMMONIATED GUINEAGRASS (*PANICUM MAXIMUM*) HAY

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ABSTRACT

Laboratory, digestion, and growth studies evaluated urea as a source of ammoniation for quality improvement in guineagrass (*Panicum maximum*) hay. Large round bales (320 kg) were reconstituted with water to yield a final moisture concentration of 25%, and treated with urea at 0, 4 or 6% of the forage DM. The urea solution was sprayed onto both flat surfaces of the bales. Each treatment was applied to three bales. Each bale was stored air-tight in individual 6-mil thickness plastic bags for 60 days. Crude protein concentration and in vitro organic matter digestion increased in a linear ($P < 0.01$) manner with increasing urea treatment level. Cell wall concentration decreased in a linear ($P < 0.05$) manner with increasing urea treatment level, although the absolute reduction was minimal.

In the digestion trial, six St. Croix White hair neutered male sheep (30 kg) were used in a replicated 3 X 3 Latin square design to evaluate the three urea treatment levels. In the growth trial, 30 sheep similar to those used in the digestion trial were allotted to six pens of five head each, with two pens assigned to the same three treatments. In the digestion and growth trials, hay intake increased in a quadratic ($P < 0.05$) manner with increasing urea treatment level. Apparent OM digestibility was not affected ($P > 0.10$), however apparent fiber digestibilities increased in a linear ($P < 0.05$) manner due to urea treatment. Linear improvements in daily gain ($P < 0.05$) and gain/feed ($P = 0.07$) were observed by urea treatment. Urea ammoniation offers potential for improving the feeding value of tropical forages, and provides an option for quality forage during the dry season.

INTRODUCTION

Efficiency of ruminant livestock production in the semi-arid tropics is severely hampered by seasonal deficiencies in the quantity and quality of available forage. Supplementation with concentrates is sometimes practiced to resolve feed deficiency during the dry season, however expense of importing grains and oilseeds which compete with human and nonruminant livestock consumption limits its widespread use. Forage conservation through hay or silage production also provides a viable option for many tropical areas, however advanced maturity of many stored forages and crop residues results in low feeding value (Ventura et al., 1975; Brown, 1988).

Chemical treatment to improve forage feeding value offers an opportunity to utilize large amounts of low quality grasses and crop residues available in tropical regions. Alkali treatment with NaOH or CaOH has increased forage digestibility, voluntary intake and animal performance (Klopfenstein, 1978; Jayasuriya, 1979). Increased forage nutritive value has also been obtained by anhydrous ammonia treatment (Gibb and Baker, 1989; Horton et al., 1991), however the response generally has not been as great as that by NaOH treatment (Garrett et al., 1979; Horton et al., 1982). An advantage of using a nitrogenous alkali compared to NaOH is that the increased microbial requirement for nitrogen when forage digestibility is increased by forage treatment is supplied by the chemical. However, limited availability and high cost of anhydrous ammonia, and increased regulation of its transportation limits its use in certain regions.

Urea is widely available in many areas, and has been used as a source of ammoniation to improve

the feeding value of various grasses and crop residues (Oji and Mowat, 1977; Hadjipanayiotou, 1982; Fahmy and Klopfenstein, 1994). The objectives of the present research were to investigate the effectiveness of urea-ammoniation for improving the feeding value of guineagrass hay.

MATERIALS AND METHODS

Sheep growth and digestion trials reported here were part of a larger project evaluating urea-ammoniation of guineagrass hay (Adjei et al., 1994). Experiments were conducted at the Agricultural Experiment Station at the University of the Virgin Islands in St. Croix, U.S.V.I. Large round hay bales (approximately 320 kg) were used. Hay was purchased from the local Department of Agriculture, and was composed of approximately 90% guineagrass, with small quantities of leucaena (*Leucaena leucocephala*), johnsongrass (*Sorghum halepense*), casha (*Acacia* spp.) and hurricane grass (*Bothriochloa pertusa*). Hay dry matter (DM) concentration averaged 87%.

Hay bales were reconstituted with water to 25% moisture and treated with urea at 0, 4 or 6% of the forage DM. The urea solution was applied by spraying onto both flat surfaces of the bales. Each treatment was applied to three bales, resulting in a total of nine bales used for the experiments. Each bale was stored air-tight in individual 6-mil thickness plastic bags for 60 days. After storage, each bale was sampled with a core sampler at approximately 20 sites. Samples were dried at 50°C, ground to pass a 1-mm screen and stored for quality analysis.

Samples were analyzed for dry matter (DM), organic matter (OM) and total N were determined according to AOAC (1984). Neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) were determined by the procedures of Goering and Van Soest (1970) and Golding et al. (1985). Cellulose (CELL) was calculated as the difference between ADF and ADL, and hemicellulose (HC) was calculated as the difference between NDF and ADF. In vitro OM digestion (IVOMD) was determined in duplicate tubes within duplicate runs by the modified Tilley and Terry (1963) procedure described by Moore and Mott (1974).

The round bales were ground through a 2.5-cm screen and stored under cover. In the growth trial, 30 St. Croix White hair neutered male sheep (30 kg) were randomly allotted to six pens, resulting in five head per pen. Two pens were assigned to each of the 0, 4 and 6% urea treatment levels. Dehydrated alfalfa (*Medicago sativa*) pellets were fed to sheep in all pens at the rate of 0.5% of body weight. A 50% (w/v) urea solution was applied at feeding time to the nontreated and 4% urea treated hays to equal the nitrogen concentration of the 6% urea treated hay. Prior to feeding, refusals of hay and alfalfa pellets from the previous day's offering were collected. Refusal of alfalfa pellets was minimal. The daily offering of hay was adjusted to approximately 120% of the previous day's intake. Daily samples of feed ingredients and feed refusal were collected and composited on a weekly basis. Sub-samples were dried in a forced-air oven at 50°C, ground to pass a 1-mm screen and analyzed for DM and OM (AOAC, 1984).

In the digestion trial, six neutered male sheep, similar to those used in the growth trial, were used in a replicated 3 X 3 Latin square design to study the same diets as those in the growth trial. Sheep were fitted with fecal collection bags and were housed in individual digestion crates (1.5 X 0.75 m). Each of the three periods consisted of a 10-d dietary adjustment phase followed by a 5-d collection phase. Sheep were fed once daily, with alfalfa pellets fed as described for the growth trial. Refusal of alfalfa pellets was minimal. Ad libitum feeding of the hays was as described for the growth trial. During the collection phase, daily samples of individual feed ingredients and feed refusals were obtained. A fecal sample representing approximately 10% of the daily fecal production was obtained. Daily samples of individual feed ingredients, feed refusal and feces were bulked over the 5-d collection period, thoroughly mixed and subsamples taken. Subsamples were dried in a forced-air oven at 50°C, ground to pass a 1-mm screen and analyzed for DM, OM, NDF and ADF as described above.

Data were analyzed by analysis of variance according to the GLM procedure of SAS (1985). Laboratory measures of forage quality were analyzed as a completely randomized design (Steel and

Torrie, 1980), with hay bale as the experimental unit. Model sums of squares were partitioned to test for the linear and quadratic effects of urea treatment level. Data from the digestion trial were analyzed as a replicated Latin square design (Steel and Torrie, 1980) with model sums of squares partitioned in square, animal, period and treatment effects. Contrast statements were prepared to test for the linear and quadratic effects of urea treatment level. Data from the growth trial were analyzed as a completely randomized design (Steel and Torrie, 1980) with model sums of squares partitioned to test for the linear and quadratic effects of urea treatment level. Pen was used as the experimental unit.

RESULTS AND DISCUSSION

Crude protein concentration of the guineagrass hay increased in a linear manner with increasing urea treatment level (Table 1). For both the 4 and 6% treatment levels, retention of added nitrogen from urea averaged 47%. Increased hay CP concentration was due to nitrogen contribution from added urea, and the degree of increased CP due to urea treatment was similar to that reported for urea treatment in other forages (Kiangi et al., 1981; Dias-da-Silva and Sundstol, 1986; Macdearmid et al., 1988) and for anhydrous ammonia treatment (Brown et al., 1987). Losses of nitrogen from added urea are volatile ammonia gas release from urea degradation (Tetlow, 1983; Williams et al., 1984a). Naturally occurring microbial urease activity in crop residues (Jayasuriya and Pearce, 1983; Williams et al., 1984b) and guineagrass (Adjei et al., 1994) has been shown to be adequate to degrade the added urea to ammonia.

Table 1. Influence of urea treatment level (% of the forage dry matter) on the chemical composition and in vitro digestion of guineagrass (*Panicum maximum*) hay.

	Urea treatment level				P value[2]	
Item[1]	0	4	6	SE	L	Q
Crude protein	5.3	7.8	10.5	.22	.01	.77
Neutral detergent fiber	74.6	74.0	72.6	.25	.03	.69
Acid detergent fiber	45.5	45.3	44.6	.34	.13	.81
Cellulose	37.3	37.5	36.4	.27	.04	.53
Hemicellulose	29.1	28.8	28.0	.25	.04	.59
Acid detergent lignin	8.1	7.8	8.2	.12	.34	.49
In vitro organic matter digestion	42.6	48.2	49.3	.58	.01	.22

[1] Crude protein (%, DM basis); Fiber values are expressed as % ash free, DM basis.
[2] Probability value for the linear (L) and quadratic (Q) effects of urea treatment level.

Cell wall (NDF) concentration was reduced by urea treatment (Table 1). Of the cell wall components, cellulose and hemicellulose were reduced by urea-ammoniation, but absolute reductions were small. In vitro OM digestion of the guineagrass hay was increased by urea treatment. In general,

alkali treatment with NaOH or anhydrous ammonia has improved forage digestibility through reduced forage NDF concentration by solubilization of the HC and(or) ADL fractions (Klopfenstein, 1978; Gibb and Baker, 1989). Increased in vitro digestion and reduced NDF concentration have been reported due to urea treatment (Tetlow, 1983; Macdearmid et al., 1988). Neutral detergent fiber concentration of untreated hay in our experiments was 70 to 75%. Fahmy and Klopfenstein (1994) also found no effect on NDF concentration (74%) but an increase in IVOMD (44 to 55%) due to urea treatment of corn stalks. Similar results reported by Kiangi et al. (1981), Hadjipanayiotou (1984) and Williams et al. (1984b) for a range of cereal straws (70 to 75% NDF) suggest that in some cases, the urea treatment effect may not be adequately described by laboratory evaluation when initial NDF concentration of the untreated forage is relatively low.

In the digestion trial, hay intake increased in a quadratic manner with increasing urea treatment level (Table 2). Apparent OM digestibility was not affected by urea treatment, but due to increased hay intake, digestible OM intake increased in a quadratic manner with increasing urea treatment level. Apparent digestibilities of NDF, ADF and HC increased in a linear manner due to urea ammoniation.

Table 2. Influence of urea treatment level (% of the forage dry matter) on the digestibility by sheep fed guineagrass (*Panicum maximum*) hay.

	Urea treatment level				P value[2]	
Item[1]	0	4	6	SE	L	Q
Intake, g OM						
Hay	510.9	614.4	572.6	20.37	.25	.05
Pellets	166.3	153.5	157.7	4.54	.18	.40
Total	677.1	767.9	730.3	22.22	.29	.05
OM digestibility, %	62.8	64.9	65.3	1.16	.90	.85
Digestible OM intake, g	424.4	496.5	475.6	14.33	.40	.05
NDF digestibility, %	65.9	69.2	70.5	.12	.03	.37
ADF digestibility, %	62.5	66.7	67.1	1.25	.04	.21
HC digestibility, %	70.9	73.4	76.3	1.11	.01	.65

[1] OM = organic matter, NDF = neutral detergent fiber, ADF = acid detergent fiber, HC = hemicellulose.

[2] Probability for the linear (L) and quadratic (Q) effect of urea treatment level.

Hay intake also increased in a quadratic manner in the growth trial (Table 3). Statistical analysis indicated that daily gain and feed efficiency increased in a linear manner with increasing urea treatment level, however numerical differences between the 4 and 6% urea treatment levels were small.

Table 3. Influence of urea treatment level (% of the forage dry matter) on the growth performance by sheep fed guineagrass (*Panicum maximum*) hay.

	Urea treatment level				P value[2]	
Item[1]	0	4	6	SE	L	Q
Intake, g OM						
Hay	1025	1294	1156	50.2	.01	.009
Pellets	306	317	309	3.6	.61	.38
Total	1330	1610	1465	52.2	.01	.008
Daily gain, g	17.3	50.8	47.7	7.48	.04	.23
Gain/feed	.013	.032	.033	.0046	.07	.47

[1] OM = organic matter.
[2] Probability for the linear (L) and quadratic (Q) effect of urea treatment level.

In the digestion and growth trials, voluntary intake of the urea treated hays was greater than that of the control, with intake of the 6% urea treated hay being less than that of the 4% urea treated hay. Observations in the field did not suggest that hay treated at 6% had a stronger ammonia odor than hay treated at 4% urea. Increased forage intake due to urea treatment has been reported (Hadjipanayiotou, 1982; Fahmy and Klopfenstein, 1994). Linear increases in intake of cereal straws have been observed with urea treatment up to 7% (Macdearmid et al, 1988) and 8% (Jayasuriya and Perera, 1982) of the forage DM.

In our experiments, apparent OM digestibility was not affected, but cell wall digestibility was increased by urea treatment. Digestible OM intake was increased resulting in large increases in daily gain by sheep. Increased in vivo digestibility of urea treated straw has been reported, but in many experiments straw was chopped, mixed with a urea solution and ensiled (Williams et al., 1984b; Fahmy and Klopfenstein, 1994). Dias-de-Silva and Sundstol (1986) treated wheat straw with urea using two methods. In one method, chopped straw (8-cm screen) was mixed with a urea solution and stored in a silo, while in another method, the urea solution was sprayed onto rectangular bales (25 kg) and the bales stored under plastic in the conventional stack method. In their experiments, voluntary intake and in vivo digestibilities of OM and cell wall components were increased due to urea treatment, with greater improvements observed in straw which had been chopped and stored in a silo compared to hay treated in the stack method. They suggested that the urea solution was more completely mixed with, and was exposed to a greater surface area in the chopped compared to the baled straw, resulting in a more effective treatment.

Results indicate that urea-ammoniation can be an effective tool for improving the nutritive value of guineagrass hay. Effects of urea-ammoniation on cell wall composition were inconsistent; however, digestible OM intake was increased by urea treatment leading to large improvements in animal performance.

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EFFECTS OF COAT COLOR ON PRODUCTION AND REPRODUCTION OF DAIRY CATTLE ON ST. CROIX

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ABSTRACT

Records obtained from a commercial dairy farm, covering a period of 26 years, were analyzed to evaluate the effect of coat color on milk production and reproduction in Holstein cows. There was no difference ($P > .10$) in the amount of milk produced during the first lactation or length of the first lactation among cows with

25, 26-50, 51-75 or > 75% black hair coat (BHC). Cows with > 75% BHC had more conceptions ($P < .009$) in January and February and fewer in March, April and June than cows with < 75% BHC ($\div 2 = 25.16$). Light colored cows (25% BHC) had shorter ($P < .03$) calving intervals than darker cows (> 25% BHC; 464 ± 14 vs 495 ± 5 d, respectively) independent of month of calving. These results indicate that milk production of Holstein cows in the tropics is not influenced by coat color but reproduction may be. Cows with more black surface area may be more susceptible to detrimental effects of heat stress because more solar radiation is absorbed as heat.

INTRODUCTION

The dairy industry is one of the major animal related agribusinesses in the U.S. Virgin Islands (USVI). A consistent supply of fresh milk for consumption or processing into other dairy food items could minimize the use of imported or reconstituted milk for human consumption in the USVI during some times of the year. Several factors, including nutrition, genetics and the environment, can influence milk production and reproductive efficiency of dairy cattle. In the Caribbean, the environment is capable of influencing both milk production and reproduction, and two components of the environment that have high potential to influence animal agriculture are ambient temperature and solar radiation.

Previous studies have shown that dairy cattle in sub-tropical and tropical conditions have depressed reproductive and productive traits (du Preez et al., 1991, 1994; Moore et al., 1992; Ray et al., 1992; Orr et al., 1993; Bagnato and Oltenacu, 1994; Howell et al., 1994). This effect was most noticeable during the warmer months of the year (du Preez et al., 1994). du Preez et al. (1991, 1994) reported that first service conception rate was negatively related to the temperature humidity index (THI). Another study showed that pregnancy rates of dairy cattle decreased from 80% to 55% when the ambient temperature increased from 26 to 27.5°C (Orr et al., 1993). Both of these studies (du Preez et al., 1991; Orr et al., 1993) show depression of reproductive efficiency in relation to ambient temperature, which is related to solar radiation.

The ability of animals to stay within their thermoneutral zone is more difficult when the animals are exposed to increased levels of solar radiation, as is the case in the Caribbean. It has been known for many years that darker colors absorb more solar radiation which leads to elevated temperatures of dark colored objects. Recently there has been interest in determining the relationship between hair coat color and production and reproduction in Holstein cows in Florida, based on the theory that darker cows will absorb more solar radiation which could lead to elevated body temperatures and increase the incidence of heat stress (Becerril and Wilcox, 1992; Becerril et al., 1993; Becerril et al., 1994).

The current project was conducted in retrospect to determine if there is a relationship between percent black hair coat and milk production or reproductive traits in Holstein cows on St. Croix.

MATERIALS AND METHODS

Records were obtained from a commercial dairy herd on St. Croix, USVI (17° 43" N 64° 40" W) covering the period from 1961 through 1986. The herd consisted of both registered and non-registered Holstein cows. The cows were bred by natural service and were exposed to bulls of the same breed throughout the year on guinea grass pastures

Data obtained from herd records included calving dates which were used to determine calving interval (CI; days; 1147 CI for 763 cows) and month of conception (n=991), milk production during the first lactation(MILK; kg; n=452) and length of first lactation(DAYS; d; n=452). Percent black hair coat (BHC) was determined using the identification pictures on herd record sheets of both the registered and non-registered cows (n=452). A grid was placed over the profile of the cow and the number of points on the grid that fell over black areas was counted. The value for BHC was determined by dividing the number of points over the black areas by the total number of points that fell within the outline of the profile of the cow. This procedure was done for both the left and right side of each cow and BHC was determined for the entire cow. The cows were arbitrarily divided into groupings based upon BHC ($\leq$ 25% (n = 8), 26-50% (n = 57), 51-75% (n = 119) and > 75% (n = 268) BHC).

Data were analyzed using General Linear Models procedures, correlation analysis, Chi-squared analysis and regression analysis with SAS for personal computers (SAS, 1987).

RESULTS AND DISCUSSION

The population of cows used in the analysis was skewed towards a darker animal. The mean, standard deviation, median and mode of BHC were 74.1, 19.7, 78.8 and 100. These values describe the same distribution of coat color as reported by Becerril and Wilcox (1992) and Becerril et al. (1994), even though they measured and reported percent white hair coat color of Holstein cows in Florida. In the present study 59% of the cows fell within the > 75% BHC group, while only 1.8% of the animals were in the $\leq$ 25% BHC group. Registered Holstein (n=314) cows produced more milk ($P < .0003$) than non-registered (n=138) cows (5025 ± 82 vs. 4497 ± 122 kg, respectively) during lactations of similar lengths ($P > .10$; 300 ± 4 vs. 291 ± 4 d, respectively). Data from registered and non-registered Holstein cows was pooled for all further analysis.

There was no effect ($P > .10$) of BHC on MILK or DAYS (Table 1). There was greater variation of both MILK and DAYS in the lighter colored cows ($\leq$ 50% BHC) due to the relatively low number of animals that were classified in these groups. Becerril et al. (1993) reported an increase of 1.9 kg in milk production for each 1% increase in white coat color in Holstein cows in Florida, while in the present study there was no significant relationship between BHC and MILK detected by regression analysis (MILK = -4.499 x BHC + 5197.4; $R^2 = .004$; $P > .2$). The numbers of cows used in these two studies were very different (4293 used by Becerril et al. (1993) and 452 used in the present study), which may explain the difference in findings. Across all BHC groups, MILK and DAYS had nonsignificant negative correlations with BHC, but MILK and DAYS were positively correlated (Table 2).

Cows with 26-50% BHC had depressed MILK ($P < .007$) when the lactation began in March through September, while cows with 51-75% BHC had lower MILK ($P < .007$) when the lactation began in July (Figure 1). Bagnato and Oltenacu (1994) reported that reproductive efficiency was lower in cows that started their lactation in the summer months when compared to cows that began lactating in the cooler times of the year. The length of first lactation had a similar pattern to that of milk production (Figure 2). Cows with 26-50% BHC tended to have shorter lactations ($P < .09$) when the lactation began in late summer, while cows with 51-75% BHC had shorter lactations (P <

.09) when the lactation began in July.

Cows with > 75% BHC had more conceptions ($P < .09$) during the months of January and February and fewer during March, April and June (Figure 3), but there were no differences during the other months of the year. Among all BHC groups there was a decrease in conceptions during the warmer months of the year. This is in agreement with du Preez et al. (1994) who reported that conception rate was maximal during the cooler months of the year and was negatively related to THI. In a previous report describing the distribution of calvings among Holstein cows on St. Croix, it was noted that the majority of cows calved during October through January (Godfrey and Hansen, 1994). In the current study the majority of cows calved during December through April. Perhaps this shift in the calving distribution is due to the fact that cows in the present study are a subset of the cows utilized in the previous study (Godfrey and Hansen, 1994).

Calving interval was shortest ($P < .03$) in cows with $\leq$ 25% BHC and longest in cows with 25-50% BHC (Figure 4). If the light colored cows ($\leq$ 25% BHC) are compared to all other cows (> 25% BHC), the CI of the lighter cows is shorter ($P < .03$) than that of the darker cows (464 ± 14 vs. 495 ± 5 d, respectively). In a previous report no relationship between BHC and CI was detected using regression analysis (Godfrey and Hansen, 1994). The reason why an effect of BHC on CI was detected in the present study may be due to the way the cows were grouped based on coat color.

In conclusion, the results of the present study show that reproductive traits of Holstein cows on St. Croix are susceptible to environmental influences to a greater extent than production traits are. Hair coat color may play a role in the sensitivity of Holstein cows to environmental influences in the tropics. Perhaps by selecting cows to be lighter in color, the negative effects of solar radiation on reproduction can be decreased. Further research needs to be done to evaluate the relationship between hair coat color and the susceptibility of Holstein cows to the effects of heat stress when exposed to elevated ambient temperatures.

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Table 1. Milk production (MILK; kg) and length of the first lactation (DAYS) of Holstein cows classified by percent black hair coat.

% Black hair coat	n	MILK	DAYS
≤ 25	8	4892 ± 621	295 ± 22
26-50	57	4996 ± 222	297 ± 11
51-75	119	4864 ± 142	301 ± 6
> 75	268	4835 ± 85	296 ± 4

Table 2. Correlation of milk production (MILK), length of first lactation (DAYS) and % black hair coat (BLACK) in Holstein cows.

Traits	R	P
MILK vs. DAYS	.78	.0001
MILK vs. BLACK	-.04	.4
DAYS vs. BLACK	-.02	.7

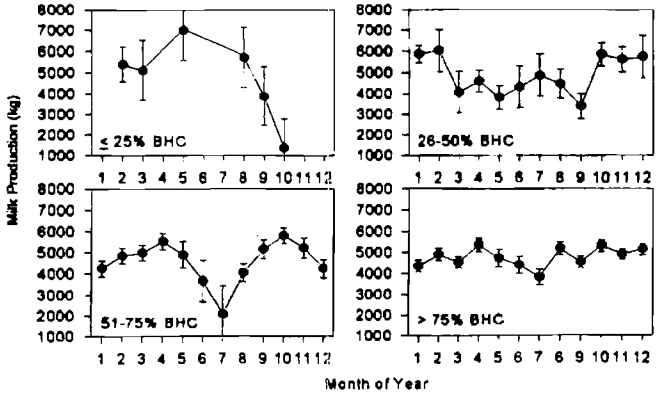

Fig. 1. Milk production of Holstein cows based on month of start of lactation (1=JAN, 2 = FEB,...) and percent black hair coat (BHC).

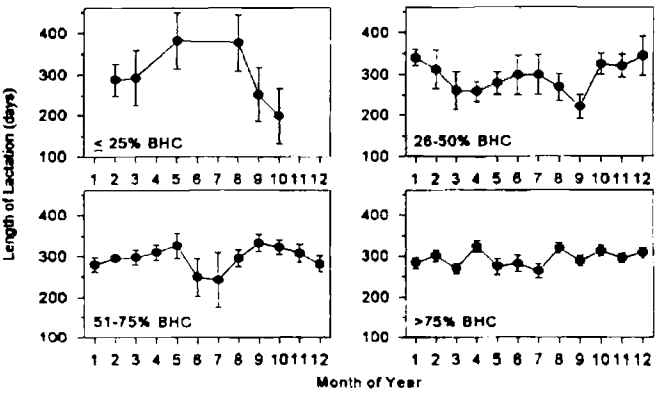

Fig. 2. Length of lactation of Holstein cows by the month of start of lactation (1= JAN, 2 = FEB,...) and percent black hair coat (BHC).

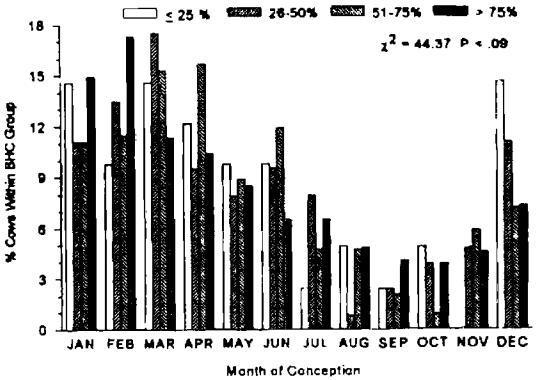

Fig. 3. Distribution of conceptions among Holstein cows classified by percent black hair coat (BHC).

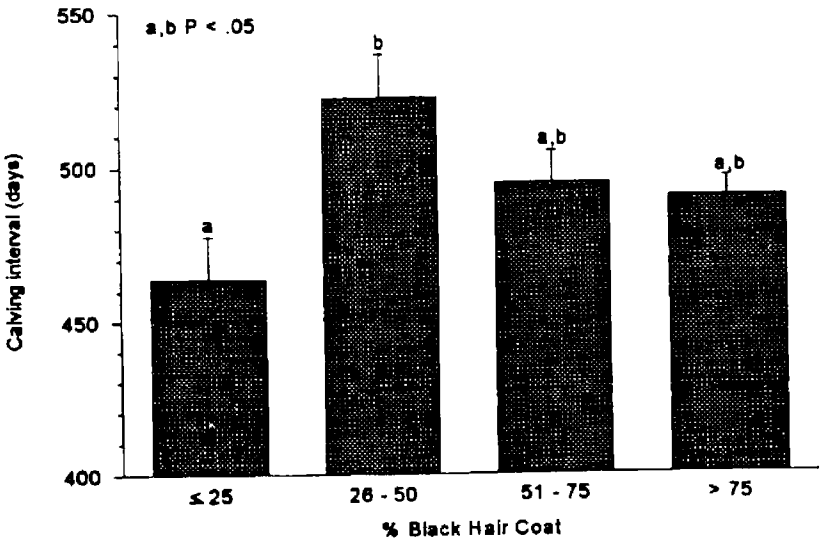

Fig. 4. Calving interval of Holstein cows differing in percent black hair coat.

THE EFFECTS OF MOISTURE, UREA LEVEL AND METHOD OF APPLICATION ON THE CHEMICAL COMPOSITION AND DIGESTIBILITY OF NATIVE GRASS HAY IN THE CARIBBEAN

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ABSTRACT

Ruminant livestock production in the Caribbean is severely hampered by seasonal deficiencies in the quality and quantity of forage and recurrent body weight losses. A series of experiments were conducted on St. Croix to evaluate the use of urea-ammoniation for improving the quality of locally produced guineagrass (*Panicum maximum*) hay. Initially, 5-kg samples of hay were reconstituted to 25 or 40% final moisture concentration and treated with urea at 0, 4, 6 or 8% of forage dry matter (DM), with or without urease addition. Urease application had no influence ($P > 0.10$) on any forage quality measure and there were no interactions between urease and moisture or urea treatments. However, increasing urea treatment level resulted in linear ($P = 0.0001$) increases in crude protein (CP) (4.2 to 18.4%) and in vitro organic matter digestion (IVOMD) (30.7 to 42.0%) of the hay. The quality improvement was greater at the 25% than at the 40% moisture concentrations. Subsequently, round bales (322 $\pm$ 25 kg) of guineagrass hay were reconstituted to 25 or 40% final moisture concentration and treated with urea (0, 4 or 6% of forage DM) by either spraying the urea solution on both flat surfaces of bales or by low pressure (10 psi) injection at five sites on each flat surface. Urea treatment increased CP and IVOMD when the urea solution was sprayed-on rather than injected into bales. Neutral detergent fiber (NDF) concentration in hay was also reduced (74.3 to 72.5%) when solution was sprayed onto the hay. A lower ammoniation effectiveness was observed at the 40% moisture concentration because of greater urea seepage losses. From these preliminary results, diets based on 25% moisture, sprayed-on, urea treated hay described above, were selected for sheep feeding trial.

INTRODUCTION

Pastures in the Caribbean Basin provide forage that is frequently deficient in both quantity and quality during the dry season resulting in reduced animal performance. Additionally, in the rainy season, when grasses are growing, energy and protein content of forage decline rapidly with maturity and low quality forage accumulates. Usually, harvesting of forage for hay is delayed in order to obtain high yields. This leads to low quality hay production in the region. The inability of native pastures to produce quality forage during cyclic dry periods was clearly demonstrated by Oakes (1969). Crude protein content of three predominant grasses in the dry season were 4.6, 3.5 and 3.4% for guineagrass, pangola grass (*Digitaria decumbens*) and hurricane grass (*Bothriochloa pertusa*), respectively. The seasonal CP content of guineagrass varied from 4.2 to 6.5% in response to a change of harvesting interval from 6 to 2 months (Oakes, 1966). A CP content of 8.13% was obtained for a fertilized guineagrass pasture at the sheep facility of the University of the Virgin

Islands (Wildeus, 1988). Crude protein content lower than 8% is known to limit forage intake and animal performance (Minson and Milford, 1967). In a 1989 survey, Boateng (personal communication) also found that hay produced on St. Croix was low in CP concentration (5.2 to 6.5%) and total digestible nutrients (51 to 59%). The poor feeding value of hay necessitated the use of dairy rations that contained more than 60% DM from imported concentrates at a monthly estimated cost of $24,500 to the three major dairies in St. Croix during the severe 1989-90 dry season. In a protein supplementation trial on St. Croix, the native guineagrass basal diet had an average CP content of 6.3% and IVOMD of 36% (Hammond and Wildeus, 1991). Five of the eight lambs on the basal diet had to be removed in the course of the 63 d trial because of severe weight losses. The remaining 'Control' lambs lost an average 56 g daily compared with an average 133 g daily gain by lambs fed the basal diet supplemented with an *ad libitum* supply of coconut meal. Since ruminants are in constant competition with monogastric animals for the supply of coconut meal in the region, alternative feed sources must be developed.

Chemical treatment of forage as a method of improving nutritive value of mature forages has been widely investigated (Tarkow and Feist, 1969; Oji et al., 1977, Klopfenstein, 1978; Brown et al., 1987; Brown, 1988). Among the chemicals used, ammonia (NH_3), in either the aqueous or anhydrous form, has received considerable attention because of its dual capability to increase crude protein content and fiber digestibility. Improvement in fiber digestibility is brought about by partial solubilization of hemicellulose, lignin and silica and the hydrolysis of uronic and acetic acid esters (Klopfenstein, 1978; Chesson et al., 1983; Sundstol, 1988). A disruption of intermolecular hydrogen bonding in cellulose is also implicated. However, the use of feed grade urea for ammoniation has greater application in the tropics where ammonia gas is largely unavailable and where farmers lack the necessary equipment to handle this unpleasant, dangerous gas. Urea treatment relies on the hydrolysis of urea to ammonia via microbial and/or plant ureases present on/in forage (Tetlow, 1983; Williams et al., 1984).

Improving the feeding value of conserved forage by ammoniation will aid in sustaining livestock production during the dry season. Most urea treatment research has been conducted with wilted or reconstituted cereal straw stored by ensiling. Little information is available concerning ureatreatment of tropical grass hay. Baseline information on levels of moisture and urea treatment and storage methods for tropical forages in the Caribbean and their influence on animal performance should be determined.

The objective of the initial experiments was to determine the effects of urea application method, final forage moisture and urea-treatment levels, and urease addition on the chemical composition and in vitro organic matter digestion (IVOMD) of guineagrass hay.

MATERIALS AND METHODS

Experiment 1. Influence of moisture concentration, urea level and urease addition on the quality of guineagrass hay.

Five-kg samples of native guineagrass hay were weighed. Based on the DM content of the hay, urea was weighed and dissolved in sufficient weight of water to reconstitute final forage moisture to either 25 or 40%, at 0, 4, 6 or 8% DM urea treatment levels. Urea solutions were thoroughly mixed with forage. Powdered urease was added in the ratio of 1:400 g of urea to half of the treated samples. Each moisture concentration (2) x urea level (4) x urease (2) factorial treatment was applied to 3 replicate samples. Treated forage was stored at ambient temperature (approximately 25 °C) in sealed, 6 mil plastic bags for 60 d. Dried, ground, initial and urea-ammoniated subsamples were analyzed for CP (Gallaher et al., 1975), cell wall components (Goering and Van Soest, 1970) and IVOMD (Moore and Mott, 1974). Data were analyzed as a completely randomized design according to the GLM procedure of SAS (1988). Model sums of squares were partitioned into main effects of forage moisture, urease addition, linear and quadratic effects of urea treatment level,

and two-way and three-way interactions between main effects.

Experiment 2A. Influence of moisture concentration, urea level and application method on the feeding value of bales of mature native grass hay.

Round bales of known botanical composition were procured from the local Department of Agriculture on St. Croix. Core subsamples of hay were drilled out of the bales for DM determination. Bales were weighed separately. Urea solutions were prepared as described in Experiment 1 to reconstitute bale final moisture concentration to 25 or 40% at urea-treatment levels of 0, 4 or 6% of forage DM. Solution was applied either by spraying half of it on each flat surface of bale or by low pressure (10 psi) injection at five sites on each flat surface. Each factorial (3 x 2 x 2) treatment was applied to 4 round bales. Treated bales were immediately enclosed in separate 6 mil plastic bags and stored in the field for 60 d. Core subsamples were drilled from urea-ammoniated bales, dried and ground. Initial and final ground subsamples were subjected to similar quality analyses as described in Experiment 1. Data were analyzed as completely randomized design. Model sums of squares were partitioned into main effects of application method, forage moisture, linear and quadratic effects of urea treatment level, and two-way and three-way interactions between main effects.

Experiment 2B

A concurrent trial was conducted in which urea levels in bales of hay were confounded with moisture application by using a common (15%) urea solution to achieve urea treatment levels (4 and 6% DM). Each method of application (sprayed-on vs. injected) by urea level (0, 4 or 6%) factorial (2 x 3) treatment was applied to 4 bales of hay. Model sums of squares were partitioned into main effects of application method, linear and quadratic effects of urea treatment level and two-way interaction between main effects.

RESULTS AND DISCUSSION

Experiment 1

Urease treatment had no influence on CP ($P = 0.14$) or on any other forage quality measure ($P > 0.57$) and there were no interactions ($P > 0.10$) between urease and other treatment variables (Table 1). The fact that quality of guineagrass hay was unaffected by urease addition has an important practical implication in the use of urea-ammoniation. Urease is an expensive item and would adversely offset the cost/benefit ratio of the treatment. However, increasing urea treatment level from 0 to 8% of DM resulted in a curvilinear increase in CP (4.3 to 18.4%) and a linear increase in IVOMD (30.7 to 42.0%). The improvement in forage CP due to urea treatment was greater at the 25% than the 40% moisture levels. Reduction in NDF due to urea-ammoniation was minor ($P = 0.13$), probably due to the lower NDF of untreated hay (75.5%) compared to that seen in some other tropical forages (Brown, 1988). Increasing urea level also lowered ($P = 0.03$) the acid detergent lignin (ADL) content in the hay at the 40% moisture treatment level (Table 1).

Experiment 2A

Average forage botanical composition of the native pasture that was cut for hay was approximately 87% DM of guineagrass, 5% leucaena (*Leucaena leucocephala*) stems, 4% johnson grass (*Sorghum halepense*), 2% casha (*Acacia* spp.) stems, 1% hurricane grass and 1% other legumes. The average round bale weighed 322 $\pm$ 25 kg with an initial DM content of 88.4%.

Crude protein, NDF and IVOMD of the untreated bales of hay averaged 5.4%, 73.7% and 41.7%, respectively. An application method x urea treatment interaction existed for CP ($P = 0.0001$), NDF

(P = 0.05) and ADL (P = 0.02) (Table 2). Urea treatment level increased CP and IVOMD when the urea solution was sprayed-on rather than injected into the bales. The NDF concentration was also reduced (74.3 to 72.5) when urea solution was sprayed onto the hay, although the absolute reduction was minor. The lower ammoniation effectiveness from urea injection was probably due to the urea solution becoming localized in the bales, in contrast to the uniform distribution from the sprayed-on treatment. Additionally, an application method x moisture x urea treatment interaction (P < 0.05) was observed for CP (Table 2). Approximately 64 kg or 164 kg of water was requiredto reconstitute a bale of hay to either 25% or 40% moisture concentrations, respectively. Substantial seepage of urea solution from bales was observed at the 40% moisture concentration, leading to a generally lower effective urea treatment level at the higher moisture concentration, even for the sprayed-on treatment.

Experiment 2B

In the concurrent experiment, approximately 75 kg (64 kg water) and 112 kg (95 kg water) of the 15% urea solution were applied to a bale of hay to achieve 4% and 6% urea treatment levels, respectively. With the average bale weight and DM content at 322 kg and 88%, respectively, final moisture concentration for treated bales were approximately 26% and 31% for the 4 and 6% urea treatment levels, respectively. Therefore, using the 15% strength urea solution to achieve the selected urea levels produced intermediate effects on forage quality of hay (Table 3) as described above for the 25% and 40% moisture levels. With increasing urea treatment level from the 15% urea solution, CP content of hay was improved from 5.4 to 8.2 and IVOMD from 42 to 48% for the sprayed-on, but not for the injected treatments (Table 3). The NDF and hemicellulose (HC) levels also decreased with increasing urea level for the sprayed-on treatment (Table 3).

CONCLUSIONS

Crude protein content in bales of guineagrass hay was doubled (5.0 to 10.0%) and IVOMD was improved (43 to 49%) from sprayed-on urea-ammoniation (0 to 6% of forage DM) at the 25% final moisture concentration, without urease application. For guineagrass hay with over 88% DM, raising the moisture level to 40% would lead to considerable seepage and urea losses, and therefore, reduced effective ammoniation. The use of appropriate urea solution strength to restrict reconstituted hay moisture concentration between 25% and 30% is recommended. Subsequent to these preliminary results, inexpensive diets based on urea-treated hay were formulated for sheep feeding trial.

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Table 1. The effects of urease addition, moisture and urea treatment levels on the chemical composition and in vitro digestion of guineagrass hay in Experiment 1.

Urease	Moisture Urea	CP	NDF	ADF	Cellulose	HC	ADL	IVOMD	
					%				
Without	25	0	4.2	77.0	49.6	39.7	27.4	9.9	31.9
		4	11.9	76.5	48.2	38.9	28.2	9.3	39.9
		6	15.5	74.1	47.8	37.7	26.3	10.0	39.2
		8	17.7	74.4	46.7	37.0	27.7	9.7	39.1
	40	0	3.9	74.9	48.6	38.1	26.2	10.5	31.7
		4	9.7	76.5	50.0	38.6	26.4	11.5	41.1
		6	12.7	73.7	47.4	37.7	26.0	10.0	45.7
		8	15.9	73.9	47.0	37.3	26.9	9.7	42.7
With	25	0	4.2	76.5	49.9	38.8	26.6	11.1	29.5
		4	11.6	74.3	45.6	36.5	28.6	9.2	41.0
		6	14.3	77.8	50.3	39.7	27.5	10.6	38.9
		8	21.0	74.1	47.5	37.7	26.6	9.7	39.6
	40	0	4.8	73.7	47.3	36.3	26.4	10.9	29.7
		4	8.7	76.0	50.5	39.7	25.5	10.8	33.3
		6	12.7	73.4	46.9	38.0	26.6	8.8	43.0
		8	19.0	73.2	46.4	37.7	26.8	8.8	46.4
SE			0.79	0.37	0.39	0.35	0.24	0.19	1.06
Probability values									
Moisture (M)			0.0001	0.13	0.85	0.05	0.66	0.62	0.38
Urease			0.14	0.75	0.84	0.87	0.94	0.76	0.57
Urea (U)			0.0001	0.13	0.10	0.78	0.51	0.03	0.0001
Ureasq			0.03	0.27	0.38	0.80	0.44	0.73	0.16
M x U			0.04	0.60	0.77	0.73	0.39	0.26	0.16

Table 2. The effects of method of application, moisture and urea treatment levels on the chemical composition and in vitro digestion of guineagrass hay in Experiment 2A.

Method of application	Moisture Urea	CP	NDF	ADF	Cellu lose	HC	ADL	IVOMD	
					g kg^{-1}				
Spray	25	0	5.3	74.6	45.5	37.3	29.1	8.1	42.6
		4	7.8	74.0	45.3	37.5	28.8	7.8	48.2
		6	10.5	72.6	44.6	36.4	28.0	8.2	49.3
	40	0	5.9	73.9	45.0	36.6	28.9	8.4	42.4
		4	6.8	74.9	46.0	38.0	28.9	7.9	45.9
		6	8.1	72.3	43.1	35.8	29.1	7.4	48.2
Inject	25	0	5.3	72.9	43.4	36.2	29.5	7.2	42.0
		4	6.7	73.4	45.0	37.5	28.4	7.5	44.0
		6	6.8	73.9	45.4	37.6	28.6	7.8	43.5
	40	0	5.7	73.5	42.5	35.9	31.0	6.6	43.8
		4	5.7	74.7	44.7	37.4	30.0	7.3	44.3
		6	6.4	74.3	43.5	35.8	30.8	7.3	46.7
SE			2.2	2.5	3.4	2.7	2.5	1.2	5.8
Probability values									
Application (A)			0.0001	0.88	0.24	0.70	0.08	0.008	0.06
Moisture (M)			0.003	0.48	0.31	0.40	0.04	0.27	0.78
Urea (U)			0.0001	0.67	0.74	0.89	0.37	0.48	0.002
Ureasq			0.08	0.14	0.16	0.06	0.65	0.68	0.98
A x M			0.13	0.42	0.66	0.69	0.15	0.67	0.19
A x U			0.0001	0.05	0.12	0.29	0.81	0.02	0.10
M x U			0.0004	0.81	0.72	0.74	0.45	0.73	0.91
A x M x U			0.05	0.75	0.97	0.54	0.79	0.17	0.70

Table 3. The effects of method of application and urea treatment level, using a common strength (15%) of urea solution, on the chemical composition and in vitro digestion of guineagrass hay in Experiment 2B.

Method of application	Urea	CP	NDF	ADF	Cellulose	HC	ADL	IVOMD
				%				
Spray	0	5.4	75.6	44.8	37.0	30.8	7.8	41.6
	4	8.0	73.0	45.8	37.3	27.1	8.5	48.0
	6	8.2	71.6	46.1	37.3	25.6	8.8	48.0
Inject	0	5.1	74.2	44.5	36.2	29.7	8.3	40.0
	4	6.7	74.9	44.9	36.8	29.9	8.1	45.4
	6	6.9	74.5	45.7	37.1	28.8	8.6	43.0
SE		0.27	0.39	0.39	0.20	0.52	0.23	0.78
Probability values								
Application (A)		0.003	0.09	0.54	0.26	0.07	0.93	0.009
Urea (U)		0.0001	0.03	0.26	0.26	0.009	0.32	0.0003
A x U		0.10	0.01	0.94	0.57	0.04	0.55	0.002

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INFLUENCE OF IMMATURE COMPOST ON GROWTH AND YIELD OF TOMATO

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ABSTRACT

Economics often encourage utilization of compost without a curing period. Tomato (*Lycopersicon esculentum*, Mill.) transplants were set into field plots 4, 11, 19, 35, and 70 days after incorporation of uncured biosolids/yard trimming compost at 135 tha^{-1}, Dry weights of plants in control (no-compost) plots from the first transplant date and fresh weights of plants from the last transplant date were greater than from compost plots. Fruit yields of control and compost plots were similar. In greenhouse flats, mean days to emergence were similar between treatments, and total emergence percentages in compost were lower than in a sandy field soil, but similar to a commercial peat-lite germination mix, Seedling shoot weights were similar between treatments, but root weight was lower in the peat-lite mix than in compost or soil. In general, utilization of the uncured compost was not detrimental to tomato plant growth or fruit yields.

INTRODUCTION

Florida's Solid Waste Act of 1988 (Chapter 88-130, Laws of Florida) mandated a 30% reduction in landfilling by Dec. 1994 and prohibited disposal of yard trimmings in landfills after 1 Jan., 1992, resulting in availability of substantial quantities of organic matter for commercial agricultural uses. A large portion of this material is being composted.

Compost maturity is important to its successful use in agriculture. Immature compost with a high C/N ratio can "rob" soil N (He et al., 1992; Poincelot 1975); high N (low C/N) may result in ammonia toxicity (He et al., 1992); lower oxygen caused by microbial activity in the root zone can damage plants (Chen and Inbar, 1993); and the curing period will permit beneficial fungi and actinomycetes to re-invade compost (Anid, 1986). Katayama et al. (1987) report that sewage sludge compost is stabilized when most of the ammonia produced during the composting process is nitrified.

In 1991 the Solid Waste Authority of Palm Beach County began a pilot program to compost biosolids (sewage sludge) and woody yard trimmings utilizing an agitated bed system. Carbon dioxide respiration tests have indicated that the compost is so stable that a curing period is not required (Byers, 1994). The objective of these experiments was to identify any detrimental effects of this uncured compost on tomato plants.

MATERIALS AND METHODS

Field expt. The first experiment was conducted on a commercial vegetable farm in Boynton Beach, FL. Soil type was a Myakka sand (sandy, siliceous, hyperthermic Aeric Haplaquod). Compost, obtained from the Palm Beach County Solid Waste Authority, West Palm Beach, Fla., was equal parts (by weight) of biosolids and yard trimmings which were composted in a bin about 14 days, and turned daily. The finished compost was 50% moisture and contained 1.50% N, 0.83% P, 0.37% K, 2.57% Ca, 0.22% Mg, 11300 ppm Fe, 337 ppm Zn, 190 ppm Cu, 78 ppm Mn, and 2245 ppm Na. Compost was manually applied to the field on 20 Aug., 1993, approximately 3 days after

removal from the composting bin, and spread on 4 separate areas 8.75 m (the width of 5 beds and the 6 alleys beside them) by 4.6 m long. Treatments were compost at 135 t ha^{-1} (fresh weight) or no compost. All plots were rototilled and beds (20 cm high, 92 cm wide, and 1.7 m, center to center) were constructed. One drip line (Netafim, Orlando, FL) was laid 2-5 cm deep in the center of each bed. Emitters were spaced at 45 cm with each delivering 18 ml min^{-1}. Irrigation was applied twice daily, with each supplying about 9340 liter ha^{-1}. Nutrients at 1.1N and 0.9K (kg ha^{-1}/day) were added through the irrigation with each application to all plots. Beds were covered with polyethylene mulch (0.0318 mm thick). Plots were 4.6 m long and consisted of 1 bed in each treatment. A randomized complete block experimental design was used with treatments replicated 4 times.

'Agriset' tomato transplants (4 weeks old) were set into 4 cm holes manually punched in the polyethylene mulch in one bed for each treatment on 24 August, 1994 (first planting). Plants were spaced 30 cm apart in two rows spaced 45 cm apart. 'Agriset' tomatoes were similarly planted into another bed in each treatment on 31 August (second planting), and 'Solar Set' tomato transplants were set into the other 3 beds on 8 and 24 September and 29 October (third, fourth, and fifth plantings, respectively). Plant population was equivalent to 39,124 plants/ha. Plants counts were taken 4-5 times and plant height (ground level to terminal bud) and stem diameter (above cotyledonary node) were measured 2-3times for each planting. About 30 days after transplanting, every other plant in each plot was excised at ground level. fresh shoot weights were measured, shoots were dried at 70C for 4 days, and dry weights were recorded.

Fruit from remaining plants was harvested and categorized into large (5 x 6 and larger), medium (6 x 6 and 6 x 7), small (7 x 7), and culls,(Hochmuth, G.J., ed., 1988), counted, and weighed. Harvest dates were as follows (1993 and 1994):

First planting: 8 Nov., 13 Dec., 30 Dec., 7 Jan., and 20 Jan.
Second planting: 16 Nov., 23 Nov., 6 Dec., 15 Dec., 1 Jan., 8 Jan., and 20 Jan.
Third planting: 17 Nov., 24 Nov., 7 Dec., 17 Dec., 4 Jan., and 17 Jan.
Fourth planting: 31 Dec. and 17 Jan.

Cooler weather slowed ripening of the last planting so that normal farming operations at the end of the season resulted in removal of the crop before it could be harvested.

Analysis of variance by transplanting dates on all measured variables was performed using the Statistical Analysis System (SAS). Treatment means were separated by Duncan's multiple range test at P 0.05.

Greenhouse experiment

Compost from the same batch used in the Field expt. was screened through a 1.25 cm screen. Treatments consisted of screened compost, a commercial peat-lite growing mix, and an Oldsmar fine sand (sandy, siliceous, hyperthermic Alfic Arenic Haplquod). Media were placed in a polystyrene tray containing 100 5 X 5 cm cells, 1 cm deep. 'Solar Set' tomato seeds were seeded, 1 per cell on 1 Nov., 1993. Flats were placed on benches in a greenhouse where mean daily low and high temperatures were 64 and 89C. A randomized complete block was used with treatments replicated 4 times. The number of seedlings emerged was counted every 24 hours, beginning 120 hours after seeding. Mean days to emergence (MDE) were calculated according to Gerson and Honma (1978):Emergence index=Sum(days to emergence)(number emerged)/total number emerged. Eleven days after seeding, 10 plants per plot were removed from trays and excised at soil level. Roots and shoots were dried at 68C for 4 days, and weighed.

RESULTS AND DISCUSSION

Field experiment

Plant heights and stem diameters were similar between treatments at each measurement date (Table 1). Fresh weight per plant was higher in the no-compost plots as compared with compost pots, and dry weights per plant were higher in the no-compost plots in the second planting.

Marketable fruit yields were lower than normal commercial production in south Florida because tomato plants were not staked and pest control was minimal. All yield and fruit size variables were similar between treatments for each planting date (Table 2). There were no growth or yield advantages to the use of the compost, probably because water and nutrients were supplied to the plants in nearly optimum amounts through the drip irrigation. Roe and Kostewicz (1990) reported that low rates of compost did not affect broccoli yields, but yields were higher with higher fertilizer rates.

Greenhouse experiment

MDE were similar between treatments, but total emergence was highest in sand and lowest in compost (Table 3). Roe and Kostewicz (1992) reported lower germination percentages of tomatoes in composts with poultry manure (another compost with a high N feedstock) than in yard trimming composts or a commercial mix.

Seedling shoot dry weights in the three media were similar, but root weights were lower in peat-lite mix (Table 3). Shoot:root ratios, which tend to be higher in plants well supplied with water and nutrients, were highest in the mix and lowest in sand.

Although immature compost has been reported to inhibit growth of cress (*Lepidium sativum* L.) (Anid, 1986), tomatoes (Hadar et al., 1985), bell peppers (*Capsicum annuum* L.) (Bryan and Lance, 1991; Roe and Kostewicz, 1992), and dill (*Anethum graveolens* L.) and radish (*Raphanus sativus* L.) (Roe and Kostewicz, 1992) there was no conclusive evidence that the elimination of the curing period for this compost resulted in any deleterious effects on tomato plant growth or yield.

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Table 1. Plant height, stem diameter, and fresh and dry weights of tomato plants grown in soil with or without 135 t/ha compost. Field experiment.

Measured trait	Transplant date				
	24 Aug.	31 Aug.	8 Sept.	24 Sept.	29 Oct.
Plant height (cm)					
Compost	24.7	30.0	65.3	32.1	37.2
No compost	22.9	24.8	65.5	31.2	37.8
	NS	NS	NS	NS	NS
Stem diameter					
Compost	6.6	5.8	11.6	6.1	6.5
No compost	6.4	5.4	11.6	5.8	6.9
	NS	NS	NS	NS	NS
Plant fresh weight (g/plant)					
Compost	390	240	515	284	231
No compost	258	304	505	238	265
	NS	NS	NS	NS	*
Plant dry weight (g/plant)					
Compost	21.2	19.8	39.8	26.5	11.5
No compost	17.4	27.3	42.6	24.3	14.5
	NS	*	NS	NS	NS

NS, * Non-significant or significant at P=0.05.

Table 2. Yields of tomato plants grown in soil with or without 135 t ha^{-1} compost. Field experiment.

Measured trait	Transplant date			
	24 Aug.	31 Aug.	8 Sept.	24 Sept.
Total weight (t ha^{-1})				
Compost	16.4	13.0	16.9	9.4
No compost	17.7	17.1	20.8	8.7
	NS	NS	NS	NS
Fruit weight (g/plant)				
Compost	1163	686	844	472
No compost	1128	1033	1154	444
	NS	NS	NS	NS
Fruit size (g/fruit)				
Compost	146	142	148	140
No compost	149	146	148	138
	NS	NS	NS	NS

NS, * Non-significant or significant at P=0.05.

Table 3. Mean days to emergence (MDE), total emergence percentages, shoot and root dry weights, and shoot:root ratios of tomato seedlings in greenhouse. Greenhouse experiment.

Medium	MDE	Total % emergence	Shoot wt (mg)	Root wt (mg)	Shoot:root ratio
Compost	12.8	67.5	7.3	3.0 a[z]	2.65 b
Potting mix	11.6	87.5	7.4	1.7 b	4.47 a
Sandy soil	11.7	93.2	5.0	3.4 a	1.48 c

[z]Mean separation in columns by Duncan's multiple range test, 5% level.

USE OF MUNICIPAL WASTE IN VEGETABLE CROP PRODUCTION

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ABSTRACT

Increase in urban population has resulted in excess accumulation of municipal waste and less space for storage. A possible means of solving this waste problem is to recycle the material in activities like vegetable gardening which have also been increasing in urban areas. To determine the feasibility of recycling municipal waste as soil amendments in vegetable crop production, experiments were designed in which composted sewage, yard waste and horse manure were incorporated into a Christiana silt loam soil and used to grow vegetables, Swiss chard (Beta vulgaris, L.), string bean (Phaseolus vulgaris, L.) and tomato (Lycopersicon esculentum, Mill). In the first of two studies, composted sewage sludge was applied at rates of 143 Mg/ha and 72 Mg/ha to the silt loam soil from 1983-1987. To test possible accumulation of toxic heavy metals in the soil and subsequent uptake in vegetable crop plants, Swiss chard was planted in the sewage treated area in 1991 in rows 6.0m long and 1.0m wide. Results showed significantly higher soil organic matter content and pH levels in plots treated with the composted sewage sludge over plots in which recommended rates of commercial fertilizer were applied. Higher concentrations of Cd, Cu, Pb and Zn were found in soils treated with sludge compost, while higher levels of Cd, Ni and Zn were found in Swiss chard treated only with commercial fertilizer. Uptake of the heavy metals in plants was not at a level that was toxic to the plants or to humans who would consume them. In another study in which beans and tomatoes were planted in plots treated with composted sewage sludge, horse manure and yard waste, fresh market and total yield of both beans and tomatoes were comparable to and sometimes greater than that produced in plots which had commercial fertilizer as the soil amendment. In one year, yields were higher in the fertilizer treated plots but although these differences were significant statistically, they were so small that they may not be of economic significance. There were also some disease problems in some plots but these problems could possibly have been solved with the proper application of pesticides.

INTRODUCTION

As urban population increases, we find that urbanized land is coming closer to farming communities. Therefore, there is a need for closer interaction between the two entities in finding solutions to common environmental and agricultural production problems. Increasing urban population has resulted in the excessive accumulation of sewage, yard, and other solid waste materials with diminishing storage space for their safe disposal. A possible solution to this accumulating waste problem would be to recycle these waste materials as soil amendments in gardening operations. By recycling waste such as sewage sludge, yard and animal waste as soil amendments in urban gardening, we will be able not only to solve our waste storage problem but also provide an economical source of N-P-K for the growth of horticultural plants. Preliminary studies have shown that municipal waste enhances soil fertility by improving structure and providing available nutrients. Sewage sludge has also been used to grow vegetables such as turnip, radish, beet, onion, lettuce and cucurbits. However, depending on the source of the sludge and soil pH, toxic elements such as Cd, Hg, Pb and Zn may accumulate in the soil and then taken up by these crop plants at levels that may be harmful to humans when they are eaten.

In addition to the accumulation of toxic elements, there is also the possibility that sludge may

contain pathogenic organisms that may contaminate plants which when eaten by humans may cause disease. Studies have shown, however, that during the composting process these organisms are destroyed. Since there are indications that if properly used, waste generated by urban population can be safely recycled as soil amendments and since urban gardening has increased among this population, it becomes necessary to conduct research to determine how well plants will grow in urban gardens in which these materials are used as major soil amendments.

MATERIALS AND METHODS

To make preliminary determinations on the level at which heavy metals from composted sludge accumulate in some vegetable crops, Swiss chard (Beta vulgaris, L.) was planted in plots of Christiana silt loam soil treated with composted sewage at rates of 143 Mg/ha and 72 Mg/ha over a period of five years (1983-1987). In 1991, Swiss chard was planted in these plots in rows 6.0m long and 1.0m wide. Rows were overplanted and after germination thinned to 5.0cm apart. Plots were laid out as a randomized complete block design with three replications per treatment. At seven weeks, whole plants were harvested by severing stems at soil surface level, washed thoroughly to remove surface contamination, and dried in an oven at 70°C for 48 hours. After drying, plant tissue was ground in a Wiley mill using a 20 mesh screen. Further preparation for heavy metal determination followed the method of Preer et al. Concentrations of heavy metals were determined on a Perkin Elmer Model 2100 atomic absorption spectrophotometer. Soil metals were determined after extraction with hot 8N nitric acid, and represent total metal levels.

In 1992, a second study was initiated in which a set of experimental plots were established where the composted waste materials, sewage, horse manure and yard waste (leaves and grass) were applied at a rate of 53 Mg/ha. Control plots received 10-10-10 fertilizer at a rate of 2.2 Mg/ha. Plots were laid out as a randomized complete block with three replications per treatment. Main plots were compost treatments and sub-plots were crop plants. Each composted material was broadcast on plot surfaces and incorporated by light discing. Crops used were string beans and tomatoes. Bean seeds were overplanted in rows and after emergence thinned to 15cm apart. For tomatoes, greenhouse grown seedlings 15cm tall were transplanted 60cm apart. Planting date was May 27 for both 1992 and 1993. There were three rows per plot and plots were 3m x 3m. During the growing season weeds were controlled by hand hoeing. No pesticides were applied. Harvesting began the last week in July for beans and the first week in August for tomatoes in both years. Frequencies of harvest were three and four days for beans and tomatoes, respectively. Fresh weight yield data was analyzed using standard statistical methods.

RESULTS AND DISCUSSION

Application of composted sewage sludge to a silt loam soil over a five year period (1983-1987) resulted in a significant increase in soil organic matter and soil pH (Table 1). While an application rate of 73 Mg/ha of composted sewage increased percentage organic matter and pH significantly over controlled plots which received only recommended rates of commercial fertilizer, doubling the application rate to 143 Mg/ha did not show further significant enhancement of these two soil properties (Table 1). Higher accumulation of heavy metals Cd, Cu, Pb and Zn in soil was greater in composted sewage treated plots than those receiving fertilizer only (Fig. I). Concentration of these metals was also higher in plots receiving the higher rate of sludge compost. Swiss chard planted in the experimental plots in 1991 showed highest concentration of Cd, Ni and Zn in control plots (Fig. II). These plots had low pH levels which are thought to have caused the heavy metals to be more available thus producing greater uptake in the Swiss chard plants. Based on toxicity levels already established in other studies (2, 3) results from this study showed that if pH levels are maintained near neutral, heavy metals are not taken up by plants in toxic proportions and therefore offer no danger to humans when consumed.

The second phase of the study in which snap beans and tomatoes were grown in field plots treated with composted horse manure, yard waste and composted sludge, results showed significant differences in both marketable and total yield for both crops. In 1992 marketable yield of beans in plots treated with composted horse manure and yard waste was comparable to that with commercial fertilizer as the soil amendment (Table 2). There was no significant production of unmarketable beans until the fourth harvest where there were some losses due to disease problems. For tomatoes, in 1992 highest marketable yield was produced in horse manure treated plots with peak production at harvests five and six (Table 3). Non-marketable tomato production was high especially in the sludge treated plots. The high incidence of non-marketable tomatoes was caused by severe disease problems. It should be pointed out that there were no pesticide applications to control disease and insect infestation in these plots.

In 1993 the highest marketable yield of beans was produced in plots treated with yard waste (Table 4). Most non-marketable yield for beans was also produced in yard waste treated plots, mostly at the second harvest (Table 4). Marketable yield for tomatoes in 1993 peaked at harvest #5 (Table 5). This period was mid-August when temperatures were high and fruits were ripening faster than when the initial harvest began. Non-marketable yield was higher than that of 1992 for all compost treatments. Since these were the same plots that were used in 1992 it is assumed that higher non-marketable yield was caused by an accumulation of disease organisms in the field plots. In addition, as in 1992, no pesticides were applied.

In general, the highest total yield for beans in 1992 was produced in plots treated with horse manure while in 1993 it was the fertilizer treated plots that had highest total yields (Table 6). However, while total yield of beans was higher in 1993 than in 1992, that of 1993 had a greater amount of the non-marketable category. For tomatoes, plants in plots treated with both sludge and horse manure produced significantly more marketable yield than control plots in which commercial fertilizer was applied in 1992 (Table 7). In 1993, fertilizer treated plots produced the highest in both marketable and total yield. However, although significant, yield in the sludge treated plots were only slightly lower. As a whole, yield results indicated that with proper application of lime and pesticides, vegetable crops such as beans and tomatoes can be successfully grown on garden plots in which composted yard and animal waste are used as soil amendments. If pH levels are near neutral there is no fear of heavy metal toxicity problems for the plants grown in plots treated with these waste materials or to humans who consume edible portions of the plants grown in soils to which these waste materials were applied.

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Table 1. Soil properties of field plots treated with composted sewage sludge over a period of four years.

	Rates of application		
Soil Properties	High (143 mt/ha)	Low (73 mt/ha)	Control (Fertilizer only)
Bulk Density (g/cm^3)	1.4[a][1]	1.4[a]	1.4[a]
Organic Matter (%)	6.2[a]	5.5[a]	3.2[b]
pH	6.2[a]	5.9[a]	4.7[b]

[1]Means followed by the same letters are not significantly different from others in the same row at P=.05.

Table 2. Harvest intervals and effect on marketable and non-marketable yield of snapbeans grown in plots treated with composted waste, 1992.

Composted Materials	Marketable yield (kg/ha) H_1[a]	H_2	H_3	H_4	H_5	H_6	Total
Horse manure	1.9	0.0	0.9	0.0	1.0	2.3	6.7
Yard (leaf+grass)	1.8	0.5	0.8	0.4	0.3	0.6	4.4
Sludge	1.7	0.4	0.5	0.8	0.3	1.3	5.0
Yard+Sludge	1.3	1.1	1.1	1.3	0.3	0.2	5.3
Fertilizer 10-10-10	1.1	0.9	0.8	0.1	0.5	1.8	6.4
$LSD_{.05}$			0.6				0.5

[a]H_1-H_6 Harvests 1-6

Table 3. Harvest intervals and their effect on marketable and non-marketable yield of tomatoes grown in plots treated with composted waste, 1992.

Composted Materials	Yield (Mt/ha) Marketable H_1[a]	H_2	H_3	H_4	H_5	H_6	H_7	Non-Marketable H_1	H_2	H_3	H_4	H_5	H_6	H_7	Total
Horse manure	3.4	3.6	2.0	3.4	13.9	29.0	7.4	0.1	2.9	0.0	1.6	1.1	0.0	0.7	43.8
Yard (leaf+grass)	1.0	0.8	0.5	0.8	2.2	0.6	1.3	0.3	0.0	0.0	0.2	0.0	0.0	0.5	8.2
Sludge	1.3	3.7	3.5	2.6	7.2	15.8	6.2	0.4	1.7	0.6	0.4	0.8	1.1	0.5	45.8
Yard+Sludge	1.0	2.5	1.1	1.8	6.3	11.8	6.3	0.3	0.9	0.0	0.6	0.6	0.2	1.6	35.1
Fertilizer 10-10-10	1.4	2.8	1.7	0.3	4.4	8.1	7.3	1.4	1.1	0.6	0.0	0.4	1.1	0.7	31.4
LSD^{05}			0.5							0.1					0.5

[a]H_1-H_7=Harvests 1-7

Table 4. Harvest intervals and their effect on marketable and non-marketable yield of bean grown in plots treated with composted waste, 1993.

	Yield (Mt/ha)												
	Marketable						Non-Marketable						Total
Composted Materials	H_1[a]	H_2	H_3	H_4	H_5	H_6	H_1	H_2	H_3	H_4	H_5	H_6	
Horse manure	0.1	1.4	0.7	1.3	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.5
Yard (leaf+grass)	0.3	1.3	0.8	1.1	0.2	0.7	0.0	0.0	0.2	0.0	0.0	0.0	4.6
Sludge	0.1	0.3	0.7	0.7	0.2	1.3	0.0	0.0	0.0	0.0	0.0	0.0	3.3
Yard+Sludge	0.2	0.7	0.3	1.1	0.4	0.2	0.2	0.0	0.0	0.0	0.0	0.0	3.1
Fertilizer 10-10-10	0.0	0.9	0.7	0.7	0.4	0.0	0.0	0.0	0.0	0.5	0.4	0.0	3.6
$LSD_{.05}$			0.6						0.3				0.6

[a]H_1-H_6=Harvests 1-6

Table 5. Harvest intervals and their effect on marketable and non-marketable yield of tomatoes grown in plots treated with composted waste, 1993.

	Yield (Mt/ha)													
	Marketable							Non-Marketable						Total
Composted Materials	H_1[a]	H_2	H_3	H_4	H_5	H_6	H_7	H_1	H_2	H_3	H_4	H_5	H_6	H_7	
Horse manure	0.1	4.6	5.6	9.4	14.2	13.0	4.7	0.1	0.4	4.3	5.1	4.6	6.7	6.7	79.5
Yard (leaf+grass)	0.5	2.4	4.1	11.9	16.5	9.4	3.2	0.3	0.9	4.0	5.2	3.9	3.9	3.1	61.7
Sludge	1.2	1.6	6.4	10.2	21.1	12.7	7.8	0.8	0.9	4.1	10.0	5.9	5.9	3.2	89.0
Yard+Sludge	2.2	6.1	5.0	8.1	6.0	0.0	0.0	4.1	1.2	5.1	7.6	8.2	8.2	0.0	61.3
Fertilizer 10-10-10	0.2	3.3	5.0	14.7	25.5	18.7	11.7	0.1	1.9	4.6	9.9	8.3	8.3	5.4	115.0
$LSD_{.05}$			0.6							0.1					0.5

[a]H_1-H_7=Harvests 1-7

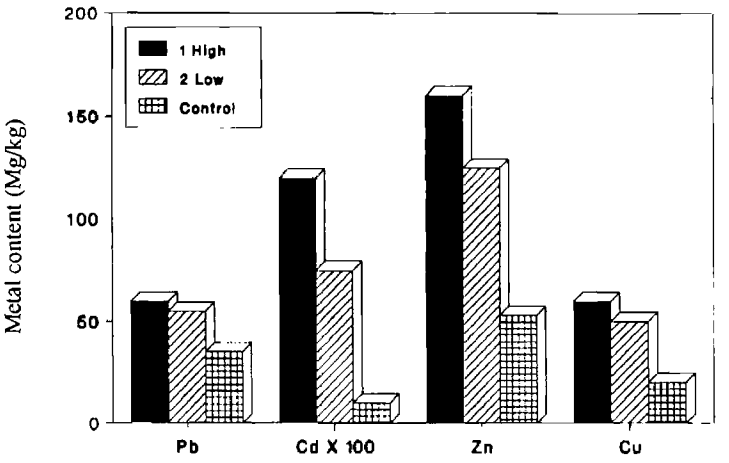

Fig. 1. Heavy metal composition in soils of field plots treated with sewage sludge (1983-1987).
[1,2] Rates of composted sewage application.
[3] Values followed by the same letters are not significantly different at p=.05.

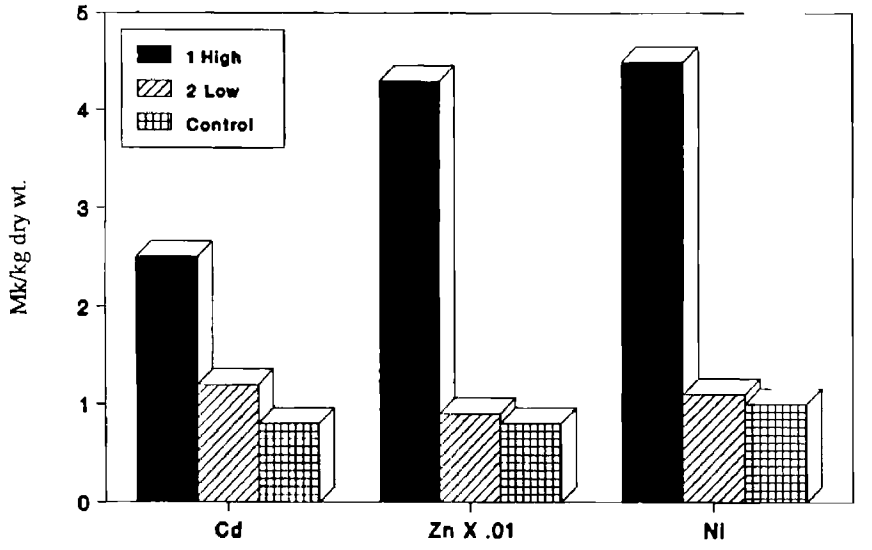

Fig. 2. Uptake of heavy metals by swiss chard grown on a soil treated with composted sewage.
[1,2] Rates of sewage application.

PIGEONPEA (*CAJANUS CAJAN* (L) MILLSP.) NUTRIENT ACCUMULATION AS INFLUENCED BY RHIZOBIUM INOCULATION AND NITROGEN APPLICATION IN ANTIGUA SOILS

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ABSTRACT

Methods which improve the nutrient status of pigeonpea plants without the addition of expensive commercial fertilizer can benefit farmers in the Caribbean and other tropical areas. Yields of this grain legume have been shown to increase significantly when the crop received adequate nutrition. Studies were conducted to evaluate the nutrient status of pigeonpea plants treated with various combinations of nitrogen fertilizer levels and Rhizobium inoculants. Rhizobium strains influenced nitrogen content of plants grown at two Antigua sites. Plants treated with strain 3384 produced nodules which were more effective nitrogen fixers than other strains tested. This resulted in higher levels of nitrogen in the stems and leaves of the tested plants. Plots treated with 45 kg/ha nitrogen showed significant reduction in nodulation. Shoot accumulation of P, K. Ca and Al was influenced by Rhizobium inoculation. Plants treated with Strain 3384 had the highest P and K accumulation and those receiving no inoculum had the highest Al content.

INTRODUCTION

The nodulation and nitrogen fixation of several tropical legumes are influenced by the availability of combined nitrogen (Summerfield, et al. 1977). The need for additional nitrogen in an effective nodulating system has also been reported (Ssali and Keya 1980). Excessive N application rates reduce N_2 fixation, decrease leaf K content and increase plant Ca and Mg content (Stewart 1969). Phosphorus has been reported to be a limiting factor in some tropical soils (Hernandez and Focht 1985). This limitation may cause reduced plant growth typical of nitrogen deficiency. Pigeonpea showed varied response to P when grown in different soil type (Hernandez et al. 1982). There are several synergistic relationships between various essential plant nutrients. Demeterio et al. (1972) reported a direct relationship between P and Zn in improving N_2 fixation. Antagonistic effects were also reported by Narwal et al. (1985). They showed that K application and absorption reduced the uptake and utilization of Ca. Increase in N_2 fixation under field conditions will result in increased N availability to present and future crops. Quilt and Dalal (1979) reported increased yield of inoculated pigeonpea grown in soils low in mineral N.

This study was conducted to determine the effect of various nitrogen levels and Rhizobium strains on the growth and nutrient accumulation of field grown pigeonpea plants.

MATERIALS AND METHODS

Pigeonpea cultivar Chaguaramas Pearl was grown at two experimental sites in Antigua. These were Betty's Hope Experimental Station and Sanderson's Farm, with soil pH of 7.6 and 7.7 respectively. Experiments were conducted as a split plot design with N as the main plot and Rhizobium as the sub plot. Each experiment was replicated 4 times and had treatments consisting of three nitrogen levels (0, 22.5 and 45 kg/ha), three Rhizobium strains and a no-inoculum treatment. The unamended soils had test results of 2.2 and 3.8% organic matter at Sanderson and Betty's Hope, respectively (Table 1). K was not applied to the experiment area, however, 40 kg/ha of P (P_2O_5) was applied preplant and incorporated to a depth of 15 cm. The appropriate N treatment was applied

uniformly over the individual 3 row plot area and incorporated to a 15cm depth. Each plot measured 1.5m wide by 6.0m long.

Three Rhizobium strains USDA 3384, USDA 3473 and USDA 3474 were obtained from the USDA Laboratory at Beltsville Maryland. They were selected for their effectiveness in producing nodules and fixing nitrogen. Rhizobium cultures were grown on yeast mannitol broth (Vincent 1970) to a population of 10^9 cells per ml and used to prepare peat base inoculant using gama radiated sterile peat (United Agri. Product, Denver, Colorado).

Surface sterilized seeds (Vincent 1970) were inoculated with the appropriate Rhizobium strain by mixing seeds with peat base inoculant. Excess inoculant was placed in the furrows before covering seeds. Seeds were planted 30 cm within row and 4 cm deep. They germinated over a 21 day period as a result of sporadic rainfall during the growing period. After germination, uniform spacing was obtained by thinning to 4 plants per meter. To avoid plot to plot contamination a 1.5 m alley was allowed on all sides of each plot. Data were taken from plants in the center row of each plot over three sampling dates. The first sample date was when 70% of the plants showed first bloom. Sampling was repeated at mid and full bloom. Whole plants were removed from the center row taking care to keep the root system intact. Leaf and stem dry weight were determined after oven drying for 48hrs. at 70°C. Dried samples were ground separately in a Stainless Steel Wiley mill to pass through a 40 mesh sieve and stored in polyethylene bags prior to elemental analysis by ICPL.

RESULTS AND DISCUSSIONS

Throughout the experimental plots at the Betty's Hope experimental station Fe chlorosis was observed. This general chlorosis could have masked nitrogen deficiency symptoms in plots receiving no nitrogen and no inoculum. Analysis of the data showed no significant interaction between nitrogen levels and Rhizobium. The leaf dry weight from both experimental sites showed that dry matter accumulation increased as nitrogen content increased (Table 2). This was also true for stem dry weight for plants growing at Sanderson's Farm. This result is contradictory to that of Hernandez et al. (1982) who showed little or no response to nitrogen application. At both sites the leaf dry weights in plots receiving 22.5 kg/ha were significantly higher than those in control plots. However, stem dry matter increased only for plants at the Sanderson site when N fertilizer was supplied. Varying reactions to added nutrient by pigeonpea has also been reported by Donawa and Quilt (1981).

Increase in N application rate did not alter the leaf nitrogen content. (Table 3). The high organic matter content at both locations (Table 1) may have influenced N uptake as shown by Dalal and Quilt (1977). Grain yield was significantly higher when plants received N than when they did not at the Betty's Hope site (Table 3). The decreased yield experienced at the Sanderson's site may have been a result of a poor response to N fertilization. This lack of yield response of pigeonpea to applied N was also reported by Hernandez et al. (1982).

The effectiveness of the introduced Rhizobium varied with strains. Plants inoculated with strain 3473 showed increased N accumulation in leaf and stem at both experimental sites (Table 4). Response to the introduced Rhizobium strains activities may have been reduced by indigenous populations of the cowpea rhizobia at Betty's Hope site. Similar results were published by Norris (1965).

Shoot accumulation of P,K,Ca and Al varied with inoculation (Table 5). Plants seemed to accumulate more of these elements when inoculated. Plants inoculated with Rhizobium strain 3384 had the highest P,K and Al content, while uninoculated plants had the highest Ca in the tissue. Norris (1959) reported that Ca has a positive influence on nodulation by affecting the infection process. This may be true for our studies with the high population of indigenous Rhizobium. Except for Al the accumulation of most nutrients in pigeonpea pods was not significantly affected by inoculation. Further research is necessary to fully understand the effects of the Rhizobium efficiency in tropical soils with varying nutrient content.

ACKNOWLEDGEMENT:

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Table 1. Soil nutrient levels at trial sites in Antigua.

Sites	pH	OM	P Bray 1	Ca	Mg	K	SO_4.S	Zn	Fe	Mn	Cu
		%	kg/ha	kg/ha	kg/ha	kg/ha	ppm	ppm	ppm	ppm	ppm
Sanderson	7.7	2.2	21.2	18480	1365	328	30.3	0.3	3.5	2.3	1.1
Betty's Hope	7.6	3.8	2.2	19712	640	397	14.3	0.3	3.9	3.3	1.4

Table 2. The effect of varying nitrogen levels on the stem and leaf dry weight g/plant of pigeonpea.

Nitrogen Levels (kg/ha)	Leaf		Stem	
	1[z]	2	1[z]	2
0	1.8	2.8	14.1	11.8
22.5	2.6	3.8	14.8	15.8
45.0	3.1	4.2	12.9	17.8
LSD 0.05	0.6	0.9	NS	3.1

[z] Research sites: 1 = Betty's Hope
2 = Sanderson

Table 3. The effect of varying nitrogen levels on the leaf nitrogen accumulation (%) and grain yield (g/plot) of pigeonpea.

Nitrogen Levels (kg/ha)	Nitrogen		Yield	
	1[z]	2[z]	1[z]	2[z]
0	2.7	3.2	1750	901
22.5	2.7	3.9	2300	825
45.0	2.4	3.4	3300	730
LSD 0 .05	NS	NS	259	158

[z] Research Sites: 1 = Betty's Hope
2 = Sanderson

Table 4. The effect of Rhizobium inoculation on the nitrogen (%) content of pigeonpea leaf and stems.

Rhizobium	Leaf Experimental Site 1[z]	2	Stem Experimental Site 1[z]	2
3384	1.2	2.8	0.8	1.1
3473	2.4	3.1	1.4	2.7
3474	1.3	1.5	0.6	1.5
0	1.4	1.6	0.8	1.3
LSD 0.05	0.2	1.1	0.3	0.7

[z] Research Sites: 1 = Betty's Hope
2 = Sanderson

Table 5. Rhizobium treatment effects on nutrient accumulation (ppm) in field grown pigeonpea shoots at Betty's Hope.

	Shoot				Pod			
Rhizobium	P	K	Ca	AL	P	K	Ca	AL
3384	2108	11182	13961	15.8	1498	11789	4201	16.0
3473	2050	11168	12731	77.3	1539	11712	4157	18.7
3474	1956	10975	13281	14.4	1527	11877	4195	13.0
0	1831	9392	14405	16.0	1480	12820	4064	13.4
LSD 0.05	156	201	558	3.5	NS	NS	NS	2.4

PHOSPHOGYPSUM USES IN AGRICULTURE

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ABSTRACT

Phosphogypsum ($CaSO_4$), a by-product of phosphoric acid production from rock phosphate is a potential source of calcium and sulfur for plants, as well as an ameliorant for alkaline and sodic soils. Phosphogypsum production worldwide exceeds 150 million Mg annually, with only about 4 percent being used in agriculture and industry and the rest being dumped into the ocean or stock piled as a waste. Florida leads in the production of phosphogypsum in the United States with an annual production of 33 million Mg and about 600 million Mg in stacks, and a projection of 1 billion Mg by the year 2000. This paper will discuss the various agronomic uses of phosphogypsum (i.e. source of nutrients for plants, conditioner for sodic soils, hard-setting clay soils and subsoil hardpans, and the acidifying benefits on high pH soils to help alleviate micronutrient deficiencies). This paper will also discuss any potential environmental hazards to be concerned with from using phosphogypsum in agriculture.

INTRODUCTION

Gypsum ($CaSO_4xH_2O$) is available for agricultural use either as mined gypsum or as a chemical byproduct. Gypsum byproducts are produced in phosphoric, hydrofluoric, and citric acid production and in pollution control systems, such as in the neutralization of waste sulfuric acid and in fluegas desulfurization. Phosphogypsum is the term used for the gypsum byproduct of wet-acid production of phosphoric acid from rock phosphate. It is essentially hydrated $CaSO_4$ with small proportions of P, F, Si, Fe, Al, several plant micronutrients, heavy metals, and radionucleides as impurities. Among the gypsum byproducts, only phosphogypsum is of worldwide importance in quantity and distribution.

Rock phosphate deposits are found throughout the world, and on these deposits the phosphoric acid industries are built. Countries with no natural phosphate deposits import the rock to produce phosphoric acid for their industry and agriculture. Therefore, the production of byproduct phosphogypsum is more widely distributed around the world than the natural deposits of rock phosphate. In fact there are over 150 million Mg of phosphogypsum accumulating annually worldwide, most of which is stacked in piles as waste material.

Byproduct phosphogypsum has a wide variety of uses throughout the world. Such uses include using phosphogypsum for road bed and embankment materials, wall board production, concrete production, animal feed supplement, soil amendment, and use as a fertilizer. This paper will concentrate on the advantages of using phosphogypsum in crop production.

IMPORTANCE OF SULFUR FOR CROP PRODUCTION

Sulfur is one of the essential nutrients required for crop production. In general, plants contain as much S as P, the usual range being from 0.2 to 0.5% on a dry-weight basis. Sulfur ranks in importance with N as a constituent of the amino acids cysteine, cystine, and methionine in proteins that account for 90% of S in plants. It is also involved in the formation of oil in crops such as peanut (Arachis hypogaea L.), soybean (Glycine max (L.) Merr.), flax (Linum usitissimum), and rapeseed (Brassica campestries).

In the past three decades, S deficiencies have been reported with increasing frequency throughout the world. The reasons given for the increasing S deficiencies worldwide are (a) the shift from low-analysis to high-analysis fertilizers containing little or no S, (b) use of high-yielding crop varieties that remove greater amounts of S from the soil, (c) reduced industrial S emission into the atmosphere due to pollution-control measures and decreased use of high-S fossil fuels, (d) decreased use of S in pesticides, and (e) declining S reserves in soil due to erosion, leaching, and crop removal. Increased consumption of S-free, high-analysis fertilizers is seen as the most important reason for the increasing S deficiency worldwide.

IMPORTANCE OF CALCIUM IN CROP PRODUCTION

Calcium with concentration ranging from 0.2 to 1.0% in plant tissue, is also essential to plant life. Calcium deficiency manifests itself in the failure of terminal buds and apical tips of roots to develop. Also, lack of Ca results in general breakdown of membrane structures, with resultant loss in retention of cellular diffusible compounds. Disorders in the storage tissues of fruits and vegetables frequently indicate Ca deficiency.

The need for Ca by plants may be readily supplied by liming materials such as calcitic and dolomitic limestone. However, lime application in large amounts on certain soils could be detrimental to plant growth. Kamprath (1971), in a review of the effect of lime on Oxisols and Ultisols, reported that lime application that raised the soil pH to 7 resulted in reduced rate of water infiltration, reduced availability of P, B, Mn, and Zn, and reduced growth of sudangrass (Sorghum vulgare var. sudanse L.), corn (Zea mays L.) and soybean. Therefore, for certain soils that need amelioration using large amounts of Ca to support commercially variable cropyields, or for crops that need large amount of readily soluble source of Ca such as peanut, a source other than lime may be necessary.

Thus, with increasing S deficiencies worldwide and the need for a Ca source other than the liming materials, phosphogypsum deserves serious consideration for agricultural applications that traditionally use mined gypsum.

CEREAL CROPS

It has been well documented that cereal crops will respond to S application when grown on soils deficient in S. Crops grown on soils which are low in organic matter, fine loamy to coarse textured, moderately - well to well drained soils with extractable soil - S of less than 7 kg SO_4-S ha^{-1} in the surface horizon tend to respond well to sulfur addition.

Studies conducted in Florida, U.S.A. have shown the addition of 1.7 to 2.2 Mg phosphogypsum ha^{-1} to increase green corn yields by as much as 107%. Other studies conducted in North Carolina, U.S.A. have shown corn response to gypsum application to be dependent upon the rate of N. At 56 or 112 kg N ha^{-1} gypsum had no effect on corn yield or N content of grain.

Studies conducted by the International Fertilizer Development Center in Togo, West Africa have also demonstrated phosphogypsum addition (10 to 50 kg S ha^{-1}) to increase corn grain yields by 44 to 77% over control plots. Similar results have also been obtained in Iraq.

Oates and Kamprath (1985) found that gypsum was as effective as ammonium sulfate as a source of S for winter wheat (Triticum aestivum L.). Plants responded to gypsum at rates from 22 to 90 kg S ha^{-1} where nonfertilized plants had S concentrations of 0.6 g kg^{-1} of dry matter and an N:S ratio of 21:1. Baird and Kamprath (1980) suggested that improved efficiency of S uptake by winter wheat from applied gypsum should occur on sandy soils by applying gypsum as a topdressing in early spring. In Bangladesh, Mazid (1986) reported that wheat yields from 1042 fertilization trials increased by an average of 21% due to gypsum applied at the rate of 20 kg S ha^{-1}.

Results from demonstration trials on the effect of 124 kg gypsum (16% S) ha^{-1} on rice (Oryza sativa L.) in Bangladesh showed that 97% of 3,368 demonstration sites responded to gypsum (Mazid,

1986). Rice yields in gypsum-treated sites increased 19 to 41% over that of the recommended NPK-fertilized plots without gypsum. Crop responses to gypsum occurred mainly in calcareous and continuously submerged soils and were more profitable in the monsoon season than in the dry season. Studies in Indonesia found that ammonium sulfate, potassium sulfate, elemental S, and gypsum were equally effective as a source of S for rice (Momuat et al., 1983). Chien et al. (1987), in a greenhouse study, demonstrated that response of rice to gypsum was not dependent on the method of application. Sulfur uptake and grain yield were not different whether gypsum was broadcast, incorporated, or placed deep into the soil.

GRAIN LEGUMES

Peanuts possess a unique nutritional habit in that supplemental Ca must be applied to the "peg", a modified stem that penetrates the soil surface to form the pod or nut. Numerous experiments have shown that supplemental Ca applied at flowering improved yield and quality of large-seeded peanuts. The role of Ca in reducing pod rot incidence in peanut is also well known. Walker and Csinos (1980) demonstrated that increasing rates of gypsum from 0.56 to 1.68 Mg ha^{-1} resulted in corresponding reduction in pod rot in five peanut cultivars.

As early as 1945, Colwell and Brady (1945) have established the superiority of gypsum over limestone in supplying the Ca requirements of peanut. Since then, the peanut-producing belt of the southeastern United States has used fine-ground (anhydride) mined gypsum, as the principal Ca source for peanut, broadcast at a rate of 0.5 to 1.0 mg ha^{-1} at first flowering when Mehlich I extractable soil Ca is <560 kg ha^{-1}.

Sullivan et al. (1974) showed that application of dolomitic limestone on peanut, based on soil test, increased soil pH and soil Ca levels but did not improve seed quality and yield. On the other hand, gypsum at 0.673 Mg ha^{-1} reduced soil pH and the detrimental effects of K on fruit yield and quality, improved seed germination, seedling survival and vigor, and increased yield and improved seed quality. Daughtry and Cox (1974) found that three commercial gypsum materials, namely; fine-ground and granular anhydride gypsum and phosphogypsum supplied at the rate of 0.76 Mg $CaSO_4$ ha^{-1} at flowering, produced no difference in the yield of Florigiant peanut. Hallock and Allison (1980) used similar commercially-formulated fine-ground (Bagged LP) and granulated (420 LP Bulk) anhydride gypsum, and granulated phosphogypsum (Tg Gypsum) as source of Ca for Virginia-type peanuts at the rate of 0.605 Mg ha^{-1}. After two years of testing (1977 and 1978), the results indicated that, in general, granulated phosphogypsum and mined gypsum were as effective as fine-ground gypsum for supplemental Ca for peanuts. When fruit matured under very dry conditions, granulated phosphogypsum and fine-ground mined gypsum were superior over granulated mined gypsum. Gascho and Alva (1990), used seven gypsum materials including phosphogypsum as a source of Ca for Florunner peanuts. They concluded that no other source of gypsum exceeded phosphogypsum in solubility, or in its beneficial effects on peanut grade and yield when broadcast at the rate of 224 kg Ca ha^{-1} at first bloom.

In Brazil, Vitti et al. (1986) reported that application of 0.1 Mg ha^{-1} of phosphogypsum to soybean on an Oxisol increased grain yield by as much as 43% and in Ultisol by 37%. At 0.25 Mg ha^{-1}, phosphogypsum increased grain yield of beans (Phascolus vulgaris L.) by 13% in Ultisol and 54% in Oxisol soil. Phosphogypsum rates used were very low so that the positive responses of the crops could be attributed more to S or Ca as nutrients than to the ameliorative effect of phosphogypsum on subsoil acidity.

SUGARCANE

Golden (1983) reported that the application of phosphogypsum at 2.24 Mg ha^{-1} to sugarcane (Saccharum officinarum L.) in Louisiana increased stubble cane yield. Breithaupt (1989), using both phosphogypsum and fluorogypsum on sugarcane at rates of 2.24 to 22.40 Mg ha^{-1}, reported

significant increases in cane and sugar yields in treated plots over the control in both plant cane and first year stubble harvests. Both gypsum byproducts were equally effective in increasing both cane and sugar yields.

FRUITS AND VEGETABLES

In Florida, phosphogypsum up to 2.24 Mg ha^{-1} applied to different varieties of citrus (Citrus sinensis) increased juice brix and reduced juice titratable acidity. It did not, however, increase fruit yield (Myhre et al., 1990). In Brazil, pineapple [Ananas comosus (L.) Merill, cv. Smooth Cayene] fertilized with phosphogypsum in combination with KCl as a substitute for K_2SO_4. Potassium sulfate-fertilized fruits, however, had better fruit juice quality than those fertilized with KCl alone or in combination with phosphogypsum. Use of raw phosphogypsum at 1.68 and 2.24 Mg ha^{-1} on various vegetable crops in 1986 in Florida increased the yields of tomatoes (Lycopersicon esculentum Mill) by 6%, potatoes (Solanum tuberosum L.) by 19%, and watermelons (Citrullus vulgaris) by 49%. Residuals from phosphogypsum applied in 1986 at 2.24 Mg ha^{-1} also increased the yields of potatoes by 22% and cantaloupes (Cucumis melo) by 42% with more number of fruits weighing 1.0 kg or more each. Pelleted phosphogypsum supplied to the 1987 crop did not increase the yields of potato and bell pepper (Capsicum annuum). The phosphogypsum pellets remained intact but soft, indicating only partial dissolution.

FORAGE CROPS

Thomas et al. (1951) demonstrated conclusively that S deficiency limits non-protein N utilization in purified diets for ruminants, and that SO_4-S as sole source of S can correct the deficiency. Hume and Bird (1970) had shown that an intake of 1.9 g S per day by sheep produced the maximum protein production in the rumen microorganisms. Bray and Hemsley (1969) showed that S supplement to the diet increased bothcrude fiber digestion and S and N retention by sheep. Application of 86 kg S ha^{-1} using ammonium sulfate to bahiagrass (Paspalum notatum Flugge) increased dry matter yield by 25%, crude protein by 1.2%, and digestibility by 3 to 4% 30 days after application (Rechcigl et al., 1989). In a larger scale, studies in Ireland (Murphy et al., 1983) showed that cattle that grazed on S-fertilized pastures could gain up to 29% more weight than those grazing on S-deficient fields. Also, for any given daily liveweight gain, S-treated area had 21% more stock-carrying capacity the first year and 19% more the second year than the untreated pasture. These studies point not only to the need for S fertilization of forage crops for yield but also to the need to achieve a desirable range of N:S ratios to assure better feeding quality forage.

In plant protein, the N:S ratio is about 15:1 and remains fairly constant. If either S or N is limiting, protein synthesis is restricted, but the protein already synthesized will have a N:S ratio of about 15:1. Excess N relative to S supply accumulates as NO_3-N, amides, and amino acids. Excess S leads to SO_4-S accumulation (Stewart and Porter, 1969). Thus the wide variation in N:S ratios.

Sulfur fertilization of forage crops almost invariably results in reduced N:S ratio in plant tissue. Lancaster et al. (1971) reported that application of S at 40 mg kg^{-1} of soil in the form of Na_2SO_4 reduced N:S ratio from 32 to 9 for orchardgrass (Dactylis glomerata L.); 45 to 19 and 72 to 14 for first and second clippings, respectively, of sudangrass; 36 to 5 for ryegrass (Lolium multiflorum L.); 27 to 8 for alfalfa (Medicago sativa L.); and 33 to 16 for clover (Trifolium repens L.). On the other hand, in an 8-year field experiment using bermudagrass [Cynodon dactylon (L.) Pers], Woodhouse (1969) had shown that despite S fertilization excessive N application could produce a forage crop with N:S ratio in excess of 60:1.

In North Carolina, use of mined gypsum applied annually on coastal bermudagrass at the rates of 28 and 56 kg S ha^{-1} increased forage yields in 7 out of 8 years of data collection (Woodhouse, 1969). In Louisiana, Eichhorn et al. (1990) reported that annual application of 108 kg S ha^{-1}, using gypsum, increased bermudagrass yield by 16% over a 4-year period, with the highest increase (29%)

occurring in the fourth year. Digestible dry matter also increased by 14.5% over the same period. In Florida, Mitchell and Blue (1989) conducted a 6-year study to evaluate the effect of gypsum applied annually on Pensacola bahiagrass at 200 and 400 kg N ha^{-1}. They reported that a low N, gypsum application did not increase dry matter yield until the fourth year, with maximum yields thereafter predicted at an annual S application between 27 and 33 kg S ha^{-1}. At high N, 10 kg S ha^{-1} increased dry matter yield in the second year. By the fifth and sixth years, maximum dry matter yield was predicted at an annual rate of 40 to 51 kg S ha^{-1}. Results also showed that Sfertilization enhanced N recovery. Maximum relative forage yield was obtained at a concentration of 1.61 g S kg^{-1} dry matter. In a one-year study in Oklahoma, application of gypsum at the rate of 64 kg S ha^{-1} decreased N:S ratio of bermudagrass forage from 11.6:1 to 7.2:1 but did not increase yield, N uptake, or improve N efficiency (Westerman et al., 1983).

To date, very few studies have been conducted on the use of phosphogypsum on forage crops. Paulino and Malvolta (1989) used phosphogypsum on andropogon grass (Andropogon gayanus cv. Planaltina) grown in pot with soil taken from a Brazilian Cerrado site. Results showed that phosphogypsum, in the absence of lime, increased regrowth dry matter yield linearly up to the maximum rate of 120 kg S ha^{-1} used in the study. Maximum protein content was attained at 63 kg S or 380 kg phosphogypsum ha^{-1}. Lime had a significant negative effect on andropogon grass. Mullins and Mitchell (1990) used phosphogypsum as a source of S at the rates of 11 to 90 kg S ha^{-1} on wheat cut for forage in Alabama. Average increases in forage yield over a 3-year period ranged from 5.4 to 9.3% for two soil series. Comparison between mined gypsum and phosphogypsum showed no difference in forage yield of wheat. Phosphogypsum applied during fall or spring had no residual effect on yield of millet [Setaria italica (L.) Beauv] or sudangrass planted for summer forage after the winter wheat crop. In Florida, use of fresh phosphogypsum as a source of Ca applied at 2.24 to 4.48 ton ha^{-1} reduced soil pH and forage yield of ryegrass to levels below those of the control. Fresh phosphogypsum can be very acidic with pH a little over 2. A 3-year study (Rechcigl and Alcordo, 1992) evaluated phosphogypsum as a source of S and Ca for bahiagrass and ryegrass, without and with 1% dolomite or calcium carbonate needed to bring phosphogypsum pH (1:1) to 5.5. Annual rates of 0.2, 0.4, and 1.0 Mg ha^{-1} are compared to single phosphogypsum application rates of 2.0 and 4.0 Mg ha^{-1}. Results showed that phosphogypsum, with or without lime, increased the two-year total forage dry matter yields of bahiagrass by as much as 28% at 0.2 to 0.4 Mg phosphogypsum ha^{-1}. Phosphogypsum, across phosphogypsum rates, with dolomite gave the highest increase in dry matter yield with 12% over the control. Application of phosphogypsum or gypsum has been shown to deplete Mg at the surface horizon (Reeve and Sumner, 1972).

CROP RESPONSE TO GYPSUM AND PHOSPHOGYPSUM ON ACID SOILS

Failure of plant roots to grow into and proliferate at deeper soil horizons in acid soils, due to toxicity, limits their capacity to take up both plant nutrients and soil moisture. Highly weathered soils such as the Oxisols and Ultisols, whose mineralogy is normally dominated by 1:1 type clay and oxides and hydrous oxides of Al and Fe, not only retain very little moisture in the surface horizons after a rain, but also dry out very quickly during short periods ofrainless days. Wolf (1975) reported that in the Cerradoes of Central Brazil corn crops can wilt after only 6 days without rain even during the wet season.

Ritchey et al. (1980) reported that gypsum contained in ordinary superphosphate (OSP) increased subsoil pH, decreased Al saturation, and increased Ca and Mg status. Roots of corn plants fertilized with OSP reached to a depth of 120 cm, while those fertilized with triple superphosphate (TSP) reached a depth of only 45 cm and wilted after 2 weeks with no rain. Pavan et al. (1984), using undisturbed profiled of Oxisols, reported that application of gypsum reduced the level of exchangeable Al and increased Ca throughout the 100-cm profile depth. Improvements in yield over time as a result of gypsum paralleled its progressive movement into the subsoil with subsequent decreases in exchangeable Al (Hammel et al., 1985). Sumner et al. (1986), based on a four-year study on the

effect of deep liming and surface application of gypsum on alfalfa, reported that gypsum at 10 Mg ha^{-1} mixed into the top soil increased dry matter yield of alfalfa by 25%. It reduced exchangeable Al and Al saturation and increased Ca throughout the 100-cm depth. Farina and Channon (1988) reported that surface-applied gypsum at 10 Mg ha^{-1} resulted in a cumulative grain yield of 3.4 Mg ha^{-1} after four cropping seasons. Progressive reduction in the level of exchangeable Al was accompanied by increased subsoil Ca, Mg, and SO_4-S. Water pH increased markedly in the zone of maximum SO_4-sorption/precipitation. Effects of gypsum on subsoil root development were striking by the fourth season. However this is contrary to the alfalfa studies of Rechcigl et al., (1987, 1988).

Studies on the use of phosphogypsum as an ameliorant for acid soils in Brazil were summarized by Shainberg et al. (1989) and Alcordo and Rechcigl (1993). Rates ranging from 0.5 to 6.0 Mg ha^{-1} of phosphogypsum significantly increased the yields of apples (Malus domestica), beans (Phaseolus vulgaris, coffee (Avabsica L.), rice, wheat, and corn. Sumner et al. (1990), evaluated gypsum and phosphogypsum applied at 5 to 10 Mg ha^{-1} incorporated into the soil in several field experiments on a range of soils in southeastern United States. The results indicate that there were no differences between the two $CaSO_4$ sources based on crop responses and soil reactions. Highly significant and economically profitable yield responses were obtained for alfalfa, corn, soybean, cotton (Gossypium hirsutum L.), and peaches (Prunus persica L.). Gypsum and phosphogypsum application enhanced root penetration and proliferation in the subsoil, where previous conditions often prevented root growth.

AMELIORANT FOR SODIC SOILS

CHARACTERISTICS OF SPODIC SOILS

In regions of the world where evapotranspiration exceeds rainfall, basic salts and carbonates move upward in the soil profile from the water table instead of downward as occurs in regions of acid soils. Rain water with its dissolved salts adds to salt accumulation in the upper horizon. Irrigation, while often necessary for crop production under arid or semi-arid conditions, can contribute to the build-up of salts in these soils, especially when the quality of irrigation water is poor. Soils containing both soluble salts and exchangeable Na at levels which interfere with the growth of most crops are classified as saline or sodic soils.

The most characteristic physical property of sodic soils is that they are highly dispersive due to Na ions in the exchange complex of the coloidal fraction, particularly the silicate clays. When placed in water of low salt concentration, aggregates from these soils imbibe water until the soil deflocculates into individual soil particles (Russell, 1973). The dispersed soil particles move down the soil profile with the water clogging the macro and micro pores to such extents that they reduce or even completely stop water infiltration through the profile (McIntyre, 1958). Upon drying, hard crusts develop at the surface which make seedlings emergence difficult. Poor hydraulic conductivity and surface crusting are the two major problems that need to be ameliorated to improve sodic soils for crop production.

USE OF GYPSUM AND PHOSPHOGYPSUM ON SODIC SOILS

Historically, mined gypsum has been used world-wide to reclaim or ameliorate sodic soils because of its abundance and low cost. The process of reclamation or amelioration of sodic soils involves (1) the replacement of Na by Ca ions in the exchange complex and (2) leaching excess Na out of the root zone. The process requires (1) the maintenance of a desired exchangeable Na fraction in the exchange complex and (2) the supply of electrolytes of a desired composition and ionic strength to the solution phase without increasing its alkalinity. The process requires the dissolution of gypsum, solute and water movement, and exchange of Na in the exchange complex with Ca ions in the solution phase.

The use of gypsum to counteract the adverse effects of surface crusts on seedling emergence has been widely recognized (Cary and Evans, 1974). In Australia, application of 4.48 and 17.9 Mg gypsum ha^{-1} to a sodic soil planted with lowland rice increased the Ca:Na ratio of both soluble and exchangeable cations. Between 1963 and 1965, an estimated 44,500 ha of fallow soils were treated with gypsum to improve dryland wheat yields in the Wimmera and Southern Mallee districts of Victoria, Australia (Sims and Rooney, 1965).

Phosphogypsum has been effectively used in the USSR to reclaim solonetz and solonitizic soils, with 3.2 million Mg used in 1988 for this purpose. Its use is expected to reach 19.2 million Mg by the year 2000 (Novikov et al., 1990). Mishra (1980), summarizing phosphogypsum research in India, which began in 1973, concluded that up to 32 Mg ha^{-1} of Indian phosphogypsum, can be used safely for reclamation of sodic soils, despite the high F content. Oster (1980), assuming a ten-fold solubility of phosphogypsum over mined gypsum, demonstrated that rate and frequency of surface application would be different for phosphogypsum than for mined gypsum at a given electrolyte concentration and rate of water application.

BULK CARRIER FOR MICRONUTRIENTS AND LOW-ANALYSIS FERTILIZERS

Micronutrients B, Cu, Mn, Zn, and Fe are applied to soils to meet crop needs in relatively small amounts. Obtaining uniform distribution of small rates is difficult. This difficulty is surmounted by bulk-blending micronutrients with granular fertilizers. From 1950 to 1980, the market share of bulk-blended fertilizers increased from 0 to more than 50% of all classes of fertilizers.(Harre and White, 1985). It is expected to continue to increase as finer delineation of the fertility status of agricultural lands is achieved requiring more custom-analysis blended fertilizers. Bulk-blended fertilizers use high-analysis fertilizers such as urea for N, which for clay-coated agricultural grade is 46% N, triple superphosphate with 20% P, and potassium chloride with 48% K. Such environmental considerations as nitrates in drinking water and eutrophication of surface waters, due to enrichment from runoff leached by N & P fertilizers may necesitate the use of locally-blended low-analysis fertilizers applied more frequently than at present. Phosphogypsum, where readily available, provides a potential bulk carrier for micronutrients and low analysis fertilizer formulations. Phosphogypsum disked into the top 10 cm of soil at a rate of 112 Mg ha^{-1} had no adverse affect on yields of corn, wheat, or soybean (Mays and Mortvedt, 1986). Pelletized phosphogypsum, enriched with micro and macronutrients, has shown promise with urea and sulfate of potash magnesia (Hunter 1989) as pelletizing agents. Also, phosphogypsum mixed with urea at 2.3 times the weight of the latter has been found to reduce ammonia loss by 85% (Bayrakli, 1990).

CONCLUSIONS

Based on the review of the literature, phosphogypsum appears to be as good as mined gypsum as a source of S and Ca for crops (Alcordo and Recheigl, 1993). In some cases surface application, appears to ameliorate subsoil Al toxicity and acidity in shorter time periods than lime. Phosphogypsum may prove to be superior to mined gypsum as an ameliorant for Al toxicity and as a conditioner for spodic soils, hard-setting heavy clay soils, and subsoil hardpans to improve saturated hydralic conductivity, surface and subsoil aggregation, and general structural development. Fluorides, which are notpresent in mined gypsum, help to detoxify Al, and acid impurities can increase the fluocculating and aggregating power of soil- and phosphogypsum-Al and -Fe, if properly exploited.

Also, phosphogypsum, where it is readily accessible, is a potential bulk carrier for micronutrients and low-analysis fertilizers. Increasing environmental demands to prevent contamination of ground water with nitrates and minimize applied N and P losses which promote rapid eutrophication of surface waters, may require the use of low analysis fertilizers in commercial agriculture as they are now commonly used in recreational and residential lawns and gardens.

Radionuclides, heavy metal impurities, and other pollutants in the order of magnitudes found in Florida phosphogypsum do not appear to constitute environmental hazards to surficial ground water, ambient atmosphere, crop tissue, or soil at rates normally used in agriculture. Based on currently available information, phosphogypsum appears to be environmentally safe as a source of S and Ca in crops and for other described uses in agriculture.

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SOIL AND WATER MANAGEMENT FOR BANANAS AND PLANTAINS IN THE WINDWARD ISLANDS

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ABSTRACT

About 22,000 farmers in the Windward Islands (Dominica, Grenada, St. Lucia, St. Vincent) supply bananas for export to Europe on a weekly basis. The terrain is mountainous, with more than 50% of banana fields having slopes greater than 20 degrees. The soils are all volcanic in origin with relatively high clay contents and, although not highly erosion-prone, the combination of steep slopes, intense rainfall and bare surfaces can lead to serious erosion. Banana cultivation is often blamed for soil erosion and siltation of streams but, managed properly, stands of bananas and plantains offer excellent protection for the soil. Low-cost operations like minimum tillage, effective drainage, thoughtful use of plant litter and maintenance of Vetiver grass lines all contribute to effective soil and water management in this cropping system.

INTRODUCTION

The banana industry of the Windward Islands (Dominica, Grenada, St. Lucia and St. Vincent) is tiny in terms of total world trade in bananas; just 3% (Borrell and Yang, 1990). Yet this amounted to 274,539 tonnes in 1992, with a value of US$140.9 million (WINBAN, 1993a) which is equivalent to 15.1% of the islands' GDP. These bananas are produced by 24,655 registered growers from 41,700 acres (16,876 hectares) giving average yields of only 6.58 t $acre^{-1}y^{-1}$. This is poor by world standards. Stover and Simmonds (1991) report yields of 68 t $ha^{-1}y^{-1}$ (27.5 t $acre^{-1}y^{-1}$) from plantations in Honduras and Costa Rica where soils, climate and management (including irrigation) are optimal.

The relatively low yield of bananas in the Windward Islands (WI) is partly an artifact of the way in which the figure is calculated. Fields drift in and out of production all the time and there is no accurate register of the area planted, so the estimate of 41,700 acres may well be too high. Nevertheless, the potential production of bananas is seldom achieved, although yields from trials conducted by WINBAN throughout the islands, using a proven package of recommended practices (WINBAN, 1993b), are usually in the range 15-23 t $acre^{-1}y^{-1}$. Yields are constrained by a combination of environmental and management factors. Reid (1993) has summarized the main physical constraints: poor soils, steep slopes, high winds, drought, inter-mat competition, flooding/waterlogging, pests and diseases. Exacerbating these problems is an interaction between poor farm management skills and expensive, scarce labor resulting in very low levels of labor productivity (Mathew, 1992; Alexander-Louis, 1993).

Of the environmental factors mentioned above, sub-optimal soil physical conditions have often been implicated as a major cause of low productivity (eg. WINBAN, 1991). All soils in the WI are volcanic in origin, parent materials being predominantly basalt, dacite and andesite. The proportion of clay in soils is high with most important arable soils in the clay and clay-loam textural categories. The predominant clay minerals vary between islands and with altitude (and hence rainfall) within islands. In the high rainfall areas of St. Vincent and Dominica allophanic soils are common whereas kaolinitic soils dominate the high altitude soils of Grenada and St. Lucia. Allophane soils are found at mid- and low altitudes in St. Vincent while soils in the other islands become kaolinitic and then montmorillonitic as one descends to sea level. Some of the most fertile

soils are alluvial deposits along the lower reaches of river valleys, particularly in St. Lucia.

Although the soils are not, in themselves, particularly erosion-prone, the combination of heavy, intense rainfall and steep slopes makes runoff and soil erosion a real danger. More than 50% of all banana fields have slopes of more than 20° and much of the banana production is on marginal land. There is little hard evidence that banana production is exacerbating the problem of soil erosion in comparison with other crops but, given the widespread distribution of the crop and its association with sensitive areas, it would be prudent to try to ensure that erosion is minimised.

Soil conservation measures are seldom popular with farmers because measurable benefits are not usually gained in the short- to medium term. Approaches involving engineering works eg. embankments and terraces are particularly unpopular in the WI because of high costs, both initially and for maintenance. However, it is feasible in a productive, humid tropical environment to rely on "soft" biological technologies which are cheaper and more user-friendly. Examples of these are:

1. the use of crop residues as a mulch and soil cover to protect the soil surface from raindrop impact and to promote infiltration of rainfall, recycling of nutrients and increase the activity of earthworms

2. planting grass lines with Vetiveria zizanioides (Vetiver grass, khus-khus grass) to slow down the rate of runoff, intercept suspended soil particles and bind the surface layers of the soil with roots.

In this paper I present the results of recent research into these two technologies and discuss various problems associated with their implementation.

CROP RESIDUES AND EARTHWORMS

Banana is a highly productive crop. Stover and Simmonds (1991) reported a probable maximum production of 400 t $ha^{-1}y^{-1}$ fresh weight of above-ground parts under optimal conditions in Panama, with an extra estimated 52 t $ha^{-1}y^{-1}$ of roots and rhizomes. About 280 t $ha^{-1}y^{-1}$ of this material is composed of pseudostems and leaves, equivalent to about 28 t $ha^{-1}y^{-1}$ dry weight. Measurements of crops in St. Lucia, where potential production is lower and crop management is less well developed, show that about 90 t $ha^{-1}y^{-1}$ fresh weight (9 t $ha^{-1}y^{-1}$ dry weight) of pseudostems and leaves are produced. A survey of the amount of this "trash" on the ground showed 7.3 t ha^{-1} dry weight ie. almost equivalent to one year's production and enough to cover the ground about eight times if spread meticulously.

There are numerous benefits associated with maintaining a layer of litter on the soil surface: raindrop- and canopy drip energies are absorbed, thereby minimising soil particle detachment and erosion; infiltration is promoted as the litter slows the movement of surface water; soil temperature is reduced; direct evaporation from the soil surface is reduced; the opportunity exists for recycling nutrients. This latter benefit can only be realised if litter is incorporated into the soil by cultivation or by invertebrates eg. termites or earthworms. In some systems eg. in the French West Indies bananas are replanted frequently and litter is ploughed into the soil. This results in a massive influx of material all at once which stimulates the rapid breakdown of soil organic matter (Godefroy and Jacquin, 1975). Cultivation is also known to reduce drastically earthworm population densities (eg. Hendrix et al., 1992; Marinissen, 1992) which in turn can depress levels of soil organic matter (Lavelle and Martin, 1992) with all the negative effects on soil structure that this entails.

Contrast this with the cropping system prevalent in the Windward Islands where the only cultivation is the excavation of a hole large enough to take the planting material. Re-planting is done every four to seven years, in the same fashion. Since inter-plant cultivation eg. to control weeds is not possible without damaging the shallow banana root system, litter accumulates steadily on the soil surface.

It has been suggested that the physical structure of many banana soils in the Windward Islands is a serious constraint to banana production (WINBAN, 1991; Reid, 1993). In particular, high clay

content, bulk densities and soil strength could result in slow drainage and impeded root growth and function. In addition, clearance of tropical forest for arable cropping is known to result in the rapid decline in levels of soil organic matter. Since organic matter content is often highly correlated with indices of good soil structure eg. aggregate stability or erodibility, its reduction is usually associated with structural degradation, erosion of topsoil and a dramatic decline in fertility.

In most environments (eg. the French West Indies mentioned above) these problems could be overcome by regular tillage which would reduce, at least temporarily, bulk density and soil strength and produce a network of pores and soil aggregates more conducive to good root performance. In mature tropical forest, where soil disturbance is at a minimum, litter and its breakdown products are incorporated into the soil by earthworms. These animals are acknowledged worldwide to be the most influential members of the soil macrofauna and there are very many reports in the literature linking them to dramatic improvements in soil structure (eg. Dexter, 1991; Lavelle and Martin, 1992; Edwards and Bater, 1992). Farmers in Europe have long recognized this fact and consider soils containing large numbers of earthworms as soils "in good heart".

So, in the absence of tillage, incorporation of litter and its breakdown products is only possible where healthy populations of earthworms exist. Such continuous incorporation avoids the periodic massive influx of material characteristic of the French system.

A preliminary, small survey was undertaken in St. Lucia to estimate the numbers of earthworms in banana fields and to test the hypothesis that their abundance was related to "trash" (ie. litter) cover. The survey was confined to the Roseau Valley, St. Lucia. Six fields were sampled; two from Model Farms (5-10 m altitude), two from around Vannard (100 m altitude) and two from around Millet (300 m altitude). Four samples were taken from each field; two from areas with trash cover and two from areas of bare soil. For each sample the edges of a 0.5 m x 0.5 m frame, constructed from galvanised steel plate, were pressed into the soil to a depth of 5 cm so as to confine an area of 0.25 m^{-2}. All trash in this area was saved, weighed fresh, dried and weighed again. The top 10 cm of soil was removed from inside the frame and all earthworms were sorted, removed by hand and preserved in formalin solution. Earthworms from below 10cm depth were collected by pouring 10 litres of dilute formalin solution (0.3%) into the frame. This solution acts as a mild irritant and any worms present make their way to the surface within a few minutes. (Only one species of earthworm (name unknown) was found during the survey, and samples were sent to Rothamstead, UK for formal identification. Results are not yet available). Three soil cores were taken from undisturbed areas adjacent to the earthworm sampling point using a stainless steel corer to extract 500 cm^3 of soil from the 0-10cm depth interval. Soil samples were taken to the laboratory and used to determine pH, % organic matter (OM), bulk density and soil water content.

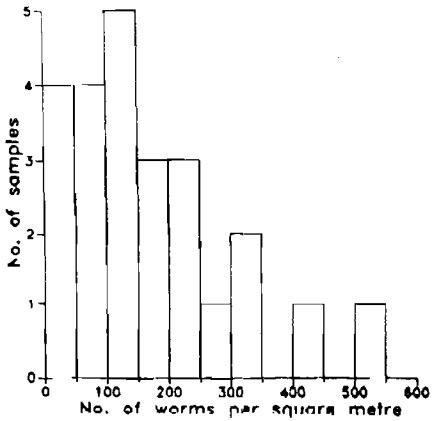

Fig. 1. Distribution of earthworm population densities from 24 samples, Rosea Valley, St. Lucia.

There were no significant differences in the number, the dry biomass m^{-2} or the individual dry biomass of earthworms in relation to altitude (Table 1) or trash presence (Table 2). Worms were found in all samples but variation between samples was large, with numbers ranging from 4 to 516 m^{-2} (Figure 1). There were, however, clear trends in relation to trash presence, with 50% more worms and 65% more worm biomass under trash. The overall mean biomass of 10.35 gm^{-2} was equivalent to more than 0.1 t ha^{-1}, a substantial amount.

Table 1. Variation in earthworm abundance and soil properties with altitude.

Variable	5-10 m	100 m	300 m	Significance
Worms m^{-2}	146.5	204.0	158.5	NS
Worm mass m^{-2} (g)	10.1	12.9	8.1	NS
D.Wt (mg $worm^{-1}$)	67.8	75.2	51.8	NS
Organic matter (%)	2.85	2.54	6.26	***
pH	4.81	3.82	3.99	*
Bulk density (g cm^{-3})	1.09	1.08	0.87	***
Water content (%)	36.4	39.5	54.1	***

Table 1 shows that organic matter content was significantly higher at high altitude whereas pH was significantly higher at the lowland sites. Bulk density was lower and soil water content higher at the upland sites, resulting from the greater rainfall at higher altitudes, but also reflecting the inverse relation between soil water content and bulk density due to differences in soil mineral composition and particle size distribution. Only soil water content was significantly greater under trash than for bare soil, although there were (non-significant) trends in other soil properties. Soil under trash tended to have larger amounts of organic matter, a higher pH and a lower bulk density (Table 2). However, there were no significant correlations between worm numbers or biomass and any of the soil properties measured.

Table 2. Variation in earthworm abundance and soil properties with trash presence.

Variable	No Trash	Trash	Significance
Worms m^{-2}	136.3	203.0	NS
Worm mass m^{-2} (g)	7.8	12.9	NS
D.Wt (mg $worm^{-1}$)	66.5	63.4	NS
Organic matter (%)	3.52	4.25	NS
pH	4.02	4.39	NS
Bulk density (g cm^{-3})	1.04	0.99	NS
Water content (%)	40.0	47.0	*

Some soil properties were expected to vary with altitude (and associated differences in rainfall and soil type) and this was found to be so in this limited, preliminary survey. The hypotheses that earthworm activity results in soil improvement and that activity and soil condition are greatest under trash cover are not supported by the data shown here. Nevertheless, clear trends showing more earthworms under trash were noted. The reason for the large amount of variation in the data is **mobility**, both of earthworms and of trash. Sampling points within fields were chosen on the basis of **current** trash incidence and adjacent bare areas were often only a few feet away. It was not possible to know if trash had recently been where there was now only bare soil, and *vice versa*.

Earthworms are also highly mobile over these distances. The only statistically significant variable with respect to trash cover was soil water content, which largely reflects current conditions. Wetter soil under trash was probably a consequence of a mulching effect.

Despite the small sample size, there were a number of important results from this survey. Earthworm numbers and biomass were found to be quite large in relation to many arable systems (eg.Hendrix et al., 1992) and comparable with those found in four samples taken from a forest site at Millet (200 earthworms m^{-2}, 12.7 gm^{-2} dry biomass). Values for organic matter were also relatively high, comparable in some cases to soils under tropical forest elsewhere (eg. Bhadauria and Ramakrishnan, 1991) although the majority had lower values around 3% perhaps reflecting the more prolonged cultivation and more intensive management at the lowland sites.

Values of pH were extremely low throughout, ranging from 3.2 to 5.9. This survey reinforced the view that most banana soils in St Lucia have become highly acidic (WINBAN, 1993a). Earthworms in general are calcicolous animals and do not normally thrive in acid soils. No relation between earthworm abundance and pH was apparent in the data, however.

Promotion of earthworm activity is easy. They thrive under the same conditions which are conducive to good banana growth. They suffer when soils dry out, when drainage is poor and in acidic soils. They require a regular supply of vegetable litter as food - banana trash appears to be ideal, particularly when spread as a mulch and soil surface protectant. So, normal, good husbandry should result in optimal conditions for earthworms which, in turn, should proliferate and improve soil conditions, initiating and sustaining an upward spiral of sustainable production. In contrast, poor agronomy discourages earthworms and promotes soil degradation. Additional samples taken from a farm where the farmer removes his trash provided only one earthworm from four samples each of 0.25 m^{-2} and soil erosion was severe.

A more serious potential threat to earthworm populations is the widespread use of pesticides, particularly nematicides since many of these chemicals affect respiratory enzymes common to nematodes and earthworms (Lardier and Schiavon, 1989; Reddy and Reddy, 1992). Any future progress on reducing pesticide usage in the banana industry is likely to improve conditions for earthworms.

No earthworms were found which had a relaxed diameter of more than 3.5 mm. The mean diameter of primary roots of banana ranges from 4.4 to 8.0 mm (Swennen et al., 1986; Delvaux and Guyot, 1989) so, although earthworm burrows will promote infiltration, their role as preferred channels for root growth is likely to be restricted to smaller, secondary roots of the banana plant. The intriguing possibility exists that the introduction of larger species of earthworm to the WI might prove beneficial to the growth of bananas.

VETIVER GRASS LINES

Vetiveria zizanioides (Vetiver grass, Khus-khus grass) is ubiquitous in all four islands, having been brought in from India early this century. It was used extensively to protect terraces in sugar cane fields but its use has ceased since bananas replaced sugar as the dominant crop. Relict populations are still found along roadsides and in gardens but it is no longer used as a tool for combating erosion except in high-risk situations eg. road cuttings. A great deal of interest in this species has been shown worldwide in recent years (National Research Council, 1993) and it is seen as an important tool for combatting soil erosion, particularly in resource-poor situations. Its utility lies in its ability to tolerate a wide range of environments, it's close-tillering growth habit and it's non-seeding character.

Conversations with banana farmers reveal their appreciation of Vetiver as a species for erosion control but they are unwilling to use it in banana fields because it takes up too much space which could be used for more banana mats. In addition, they say that it grows poorly under the shade of the banana canopy, seldom persisting for more than a year. These two problems have been investigated at WINBAN R&D and results are presented below.

A well-grown stand of bananas produces a dense canopy. Stover and Simmonds (1991) reported

values of leaf area index for banana from 2.4 to 4.7 although these depend very much on variety, planting density and stage of the cropping cycle. A series of measurements was taken under a banana canopy in St. Lucia by repeatedly walking a 40 metre transect through the crop while holding a portable light meter. The crop was a 'Robusta' second ratoon stand, spaced eight feet between rows, seven feet within rows which were oriented east-west. Readings were taken at ground level every two metres and compared with values recorded in direct sunlight.

Mean values of fractional transmittance are shown in Table 3, together with minimum values recorded at each time. Under this particular canopy, which was fairly typical of banana stands in the WI, about 40% (27-65% depending on the time of day) of the incident light reached the ground but this was highly variable, with some areas occasionally receiving only 3-7%.

Table 3. Diurnal variation in transmission of light through a banana canopy.

Time	Mean fractional transmission	Minimum fractional transmission
0830	0.33	0.04
1030	0.65	0.06
1230	0.52	0.07
1430	0.27	0.03

If Vetiver is to flourish with bananas, it must be shade-tolerant or the banana canopy must be manipulated to allow more light to penetrate to the understorey. The growth of the Vetiver clone available in St. Lucia was tested under a range of shade conditions. Three tillers or "slips" were planted in each of 80 plastic pots each containing 2.5 litres of a clay-loam soil taken from the WINBAN farm. Two replicate blocks of four shade environments were constructed using various combinations of shade netting suspended from wooden frames to give mean daily shade values of 7%, 35%, 60% and 75% of incident light. Ten pots were allocated at random to each shade/block combination. Since many of the banana soils in the WI are acidic, and this soil had a pH below 4.0, five of the ten pots in each shade/block combination were limed, using ground calcitic limestone, at a rate equivalent to 8 t ha^{-1}. The experimental design was thus a randomized complete block with two blocks and four shade treatments, incorporating a split-plot treatment of with/without limestone. Pots were kept well-watered and the Vetiver was allowed to grow for 140 days after which it was harvested. The number of tillers was counted and fresh- and dry weight of the shoots were measured.

Figure 2 shows the inhibition of shoot growth when Vetiver is grown in shade and the difference that the addition of lime to this acid soil made to this response to shading. Analysis of variance showed that the effect of shading was highly significant (P=0.004) whereas the effect of liming was not. Nevertheless, the effect of lime was very consistent across all shade treatments. The mean dry matter production at 60% shade (ie. a fractional transmission of 0.4 in Table 3) was only about 45% of that in full sunlight.

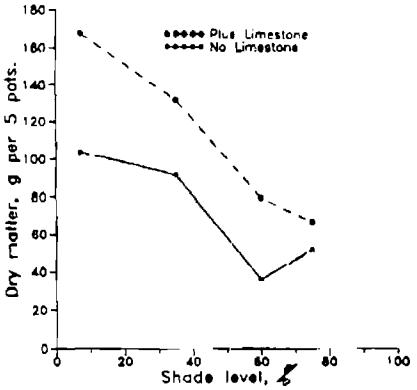

Fig. 2. Aerial growth of Vetiver grass under different levels of shade.

Differences in shoot dry matter were directly proportional to the number of tillers produced (Figure 3). This is important because the ability to filter surface-flowing water depends on the distribution of shoots at, or near, ground level. Thus shading directly affects that aspect of Vetiver growth which is most important for its effectiveness in controlling erosion.

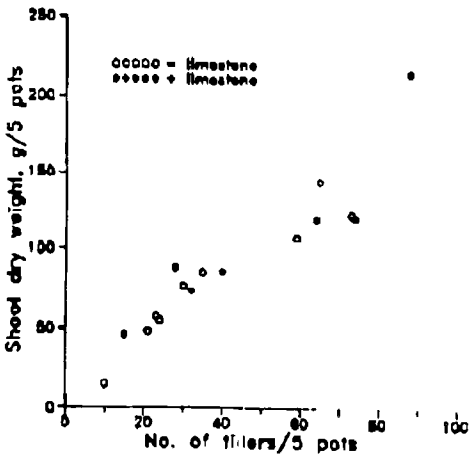

Fig. 3. Relation between Vetiver shoot dry weight and number of tillers.

It appears that the shade cast by bananas planted in standard arrangements is unsuitable for vigorous growth of Vetiver. We are left with two options: find clones of Vetiver (or other non-seeding grasses with vigorous tillering habits) which are less sensitive to shade, or manipulate the planting pattern of bananas to allow the Vetiver clone we have to grow vigorously. Attempts are being made to find and test other Vetiver clones for shade tolerance. Apparently, such material is available in Thailand (Disnada Diskul, pers. comm.). However, modifying banana spacings on each side of a grass line appears to be possible without reducing overall population densities or banana yields. Sample configurations are shown in Figure 4 for two commonly-used planting arrangements. Both modifications result in minor "local" overcrowding but early observations and results suggest that there are no harmful effects on the bananas and that the extra light available to

the Vetiver is enough to allow vigorous growth.

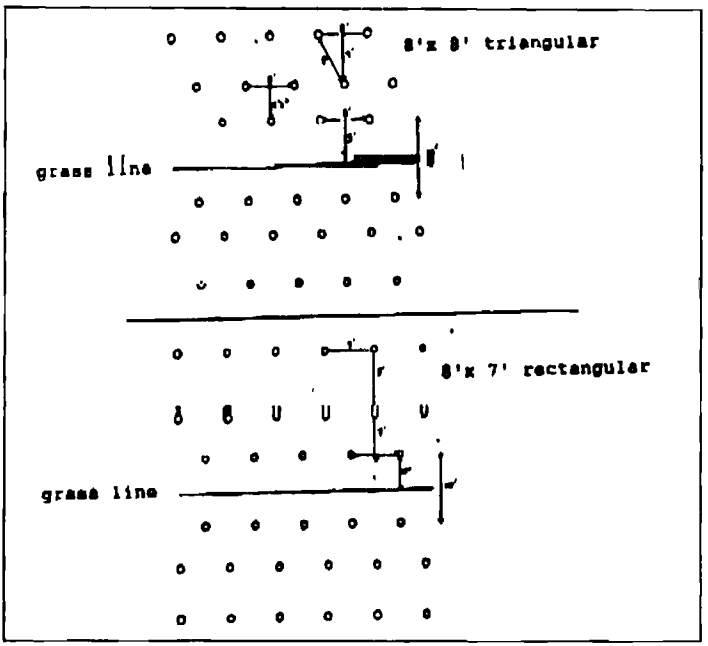

Fig. 4. Modified planting geometry for bananas to allow establishment of Vetiver grass lines.

The space taken up by the grass line is not a problem if the traditional method of planting Vetiver is modified. In the WI bunches of 'slips' ie. tillers have always been planted about 30-50 cm apart. This results in large clumps of the grass with wide gaps between the clumps. In order to achieve a useful barrier to surface-flow several lines, with clumps overlapped, are needed. This results in a wide grassline which takes up a lot of space. WINBAN has developed a system in which two or three tillers are planted 5-10 cm apart which results in a single, but effective, line without large gaps.

CONCLUSIONS

The technologies described above are simple and cheap to use. Covering the soil surface with banana trash protects the soil from erosion and helps to maintain, directly and indirectly through the promotion of earthworm activity, soil structure and fertility. Establishment and maintenance of Vetiver lines also reduces erosion and promotes infiltration of rainwater, which might have important consequences for production in lowland areas during the dry season although this is not yet proven.

Yet there are problems. On steep hillsides trash is quickly moved downslope by runoff and farmers usually pile it up, saying that it interferes with the application of chemicals if it is spread out and that it clogs drains. Farmers are also reluctant to introduce grasslines as it interferes with workers' movement up and down slopes. It also harbours rats, they say, and anyway it's a grass and grasses are weeds.

The real problem is that, although people pay lip-service to the notion that combating erosion is

a good idea, the consequences of not doing so are too far in the future. We, as scientists, must demonstrate more tangible benefits from land management practices such as these if we are to see them adopted.

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RESPONSE OF SELECTED VEGETABLE CROPS TO SALINE WATER IN THE U.S. VIRGIN ISLANDS

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ABSTRACT

A series of greenhouse experiments was conducted to determine the effects of different sea water concentrations (0, 10, 20, 40, and 80%) on the growth of tomatoes (*Lycopersicon esculentum* L. var. Heatwave), bell pepper (*Capsicum annuum* L. var. California Wonder), and sweet basil (*Ocimum basilicum* L.) at two different statges of growth (seedling and reproductive). Results indicated that each of the crops can tolerate different levels of saline water without significant reduction in growth. Tomatoes exhibited tolerance to 40% sea water at the seedling stage and 20% at the reproductive stage. Bell peppers were tolerant to 20% sea water at the seedling stage and 40% at the reproductive stage. Basil displayed tolerance to 40% sea water at the seedling stage and 80% at the reproductive stage. In all experiments, the electrical conductivity (EC) of soil extracts increased with increasing concentration of sea water. This study would suggest that at certain concentration, saline water can be utilized to irrigate selected vegetable and herb crops with economic importance in the Virgin Islands.

Key words: salinity, *Lycopersicon esculentum, Capsicum annuum, Ocimum basilicum*

INTRODUCTION

Limited water resources are a major constraint for vegetable production in the Virgin Islands and most of the Caribbean islands. Surface water is available seasonally and dependent on the amount of rainfall and run-off. Although the long term average annual rainfall is more than 1000 mm, potential evapotranspiration exceeds rainfall in more than 80 percent of the year. High evapotranspiration rate is attributed to high temperatures, strong solar radiation and relatively constant wind movement.

The most common source of irrigation water is rainfall collected and stored in closed cisterns. Most of the ground water in the islands contains high levels of salt, and is therefore not suitable for domestic use. Some farmers use well water, if it is not too brackish. Many wells have an initial salt levels that are acceptable for irrigation use.

Increasing the water supply for irrigation by developing or tapping into other sources may have a great impact in stimulating local production of vegetable and other food crops with high economic value. The potential use of brackish ground water for irrigation has never been explored in the Virgin Islands. As available water supplies decrease, interest in using brackish or saline water for agriculture has increased.

The objectives of this study are to: 1) evaluate the effect of different levels of salinity on plant growth and yield; 2) establish the salt tolerance threshold of important vegetable crops and herbs in the U.S. Virgin Islands; and 3) determine the effect of saline water on soluble salt accumulation in the soil.

RELATED STUDIES

Due to the high cost involved in saline water conversion, research emphasis on the use of saline water for irrigation has focused mainly in such areas as methods of irrigation (4), soil management (9, 13), breeding for salt tolerance (6, 17, 20), and maintenance of salt balance (21).

The effects of salinity on vegetable crops have been widely studied (2, 5, 11, 24). Vegetable crops differ in their response to salinity of irrigation water. Some research indicates that excess salinity reduces the amount and rate of plant growth. Broccoli is more tolerant than tomato and cucumber, while cantaloupe is almost as tolerant as sugar beets (2). The effects of salinity on herbs have not been widely studied.

Mitchell et al. (15) reported that irrigation with saline water had no effect on total fresh yield of processing tomatoes, but slightly reduced fruit water content which resulted in increased fruit acid concentration. Saline water has been used to improve fruit quality of tomatoes grown in nutrient film culture (8), on sand dunes (16), and under field conditions (14, 15, 18, 22). The improvements gained by saline water are usually accompanied by reduced yields (1, 22).

In California, there is increasing interest in using saline drainage water to supplement other sources of irrigation water, especially in areas with limited water supplies and excessive amounts of saline drainage water (3). This interest is also shared by many farmers in the U.S. Virgin Islands.

In most cases, water with salt levels higher than 2100 milligrams of salt per liter is considered unacceptable for irrigation (23). Hall (10) reported that in addition to salt content, other factors such as the concentration of sodium in relation to other cations and anions, especially carbonate and bicarbonate has a negative effect on the plant. The water in most St. Croix wells is brackish and high in sodium chloride and sodium bicarbonate with a dissolved solid content averaging from 1500 to 3000 mg/l (12, 19). Although salt tolerance has been established for many vegetable crops, no studies have been conducted in the semi-arid, subtropical climate and high pH soils of the U.S. Virgin Islands.

MATERIALS AND METHODS

Greenhouse studies were conducted in 1993 and 1994 to evaluate the effect of different levels of salinity (sea water concentrations) on plant growth, establish the salt tolerance threshold of tomato, pepper and basil at seedling and flowering stages, and determine the level of salinity (soluble salt accumulation) in the soil.

Seedling Stage

Seeds of tomato, pepper and basil were germinated in styrofoam trays containing a Pro-Mix potting medium. Seedlings were then transplanted at 21 days after sowing to 1-gallon plastic pots lined with gravel and filled with field soil. The plants were treated with various concentrations of saline water prepared by diluting 100 percent sea water with municipal fresh water. Each plant was treated (watered) with various sea water concentrations of 0, 10, 20, 40 and 80 percent. These concentrations resulted in electrical conductivity (EC) readings of 0.05, 7.5, 13.7, 25.8 and 46.0 dS/m, respectively. Application of sea water started one week after transplanting. The application rate was 250 ml/pot/day for a period of 4 weeks.

Flowering Stage

Seedlings of tomatoes, peppers and basil were grown in 2-gallon pots until flowering stage. The plants were then applied with sea water of similar concentrations with that used at the seedling stage experiment. Similar procedures and design were followed as in the seedling trial, however, sea water was applied at 500 ml/pot/day for a duration of 4 weeks.

Experimental Design and Data Collection

The pot experiments were arranged in a completely randomized design. Each treatment consisted of 5 pots planted to one plant per pot. Each pot was a replicate. The pots were moved around every week to reduce variations due to border effects. For each experiment, plant height was measured once every week. At the end of the experiment, total plant fresh and dry weights were recorded. Roots were separated, weighed and oven-dried for dry matter content. The electrical conductivity of sea water dilutions was read every week using the YSI Model 33 Salinity-Conductivity-Temperature Meter. Initial EC of soil solution was determined using the Solu-Bridge Conductivity meter. After the experiment, soils were sampled for EC determination. EC readings reflect the salt accumulation in the soil after repeated applications of various sea water concentrations. All data were analyzed for statistical significance using the regression analysis by Statistical Analysis System (SAS).

RESULTS AND DISCUSSION

Tomato - Seedling Stage

Seedling height decreased linearly with increasing sea water concentration (Fig. 1). Height was almost similar in seedling treated with 0, 10 and 20% sea water indicating that tomato can tolerate up to 20% sea water at seedling stage. Increasing sea water concentration to 40% significantly decreased seedling height. All seedlings died at sea water concentration of 80% (Fig. 1). Similar effect was observed in tomato plant fresh and dry weights (Fig. 2). Fresh and dry weights decreased as sea water concentration increased. Small differences were observed between 0, 10 and 20% sea water. Seedling weight decreased more than 50% when treated with 40% sea water (Fig. 2). Soil soluble salts as measured in terms of electrical conductivity (EC) increased linearly with increasing applications of sea water (Fig. 3). EC increased from 1.5 dS/m at 10% sea water to maximum of 6.0 dS/m at 80% sea water. An EC reading of 1.5 dS/m may be tolerable for some vegetable crops, among them is tomato. A significant linear response was observed between sea water concentration and EC of the final soil solution (Fig. 3). This would indicate that continuous application of sea water will definitely increase salt accumulation in the soil.

Tomato-Flowering Stage

There was a significant linear response in plant height of tomato treated at flowering stage throughout the duration of the experiment (Fig. 4). Plant height linearly decreased as sea water concentration increased. Plants tolerated sea water concentration of 20% as differences in plant height were small between 0, 10 and 20% sea water. Except at the 5th week, plant height was suppressed by application of sea water at higher concentrations (40 and 80%) as shown in Fig. 4. Both plant fresh and dry weights linearly decreased as application of sea water concentration increased (Fig. 5). The effect was apparent at 40 and 80% sea water. A sharp decrease in fresh weight was observed with increasing sea water concentration. Small differences in dry weights were seen among treatments of 0, 10, and 20%. Although there was a significant linear decrease in root fresh weight with increasing sea water concentration, this response was not observed in root dry weight (Fig. 6). Results were variable as the treatment with 20% and 80% have lower fresh and dry weights compared to treatment with 40%. Thus, in terms of plant fresh and dry weights, tomato can tolerate sea water concentration up to 20%. Roots are sensitive to 20% sea water application.

Sea water concentrations did not affect tomato flower and fruit development (Table 1). However, the number of flowers was lowest at the 80% sea water treatment. Optimum flower development was observed at sea water concentration of 20% (Table 1). Although there was a decreasing trend in fresh and dry weights of tomato fruits, the response was not significant. The data would indicate that for fruit development, tomato can tolerate higher concentration (80%) of sea water. The final EC of soil solution remained almost constant at 0 to 20% sea water application (Fig. 7). This would indicate that tomato may have absorbed some of the salt in the soil solution. The EC

reading drastically increased at applications of 40 to 80% sea water. Maximum EC reading of 5.0 dS/m was reached at 80% sea water which was lower than that observed at seedling stage. A significant r^2 value of 0.94 was obtained between the final EC of soil solution and sea water concentration (Fig. 7).

Pepper - Seedling Stage

There was no significant linear response in plant height of pepper seedlings treated with sea water concentrations (Fig. 8). This suggests that pepper is insensitive to sea water applications at seedling stage and can tolerate higher concentrations of saline water. Both fresh and dry weights of pepper seedlings linearly decreased with increasing concentration of sea water (Table 2). Significant decrease in fresh and dry weights was noted starting at 40% sea water. In terms of plant fresh and dry weights, the data show pepper seedling tolerance to sea water up to 20%. Fresh and dry weights of roots were not significantly reduced by sea water concentration which suggests that roots are less sensitive to sea water than shoots (Table 2).

As with tomato, application of increasing sea water concentration to pepper seedlings resulted in a linear increase in soil salinity (Fig. 9). There was a rapid rise in soil EC starting from application of 10% sea water. This implies that when pepper is treated with sea water at seedling stage, there is a rapid build-up of salt in the soil. This is probably due to higher tolerance of pepper seedlings by not absorbing salt in the soil.

Pepper - Flowering Stage

Application of sea water concentrations to pepper at flowering stage resulted in a significant linear decrease in plant height with increasing concentration (Table 3). Tolerance threshold in terms of plant height appears to be at 40% sea water. Three weeks after planting, all plants treated with 80% sea water did not survive (Table 3). As shown in Table 4, fresh and dry weights of plants, roots and fruits decreased in a linear response to increasing sea water concentrations. For plant dry weight, the tolerance threshold is at 40% sea water. For root fresh and dry weights the threshold is at 20% sea water. This was also similar with fruit fresh and dry weights. The data in Table 4 suggest that peppers can tolerate sea water applications up to 40% at flowering stage.

There is a significant linear response (r^2=0.9908) of soil salinity (final EC) to sea water concentrations (Fig. 10). Accumulation of salt in the soil is relatively higher in pepper than tomato as shown in the steepness of the slope (Fig. 10). Final EC of soil solution reached to a maximum of 14 dS/m at 80% sea water. This implies that the use of saline water for irrigating pepper may result in rapid salt build up in the soil.

Basil - Seedling Stage

Plant height of basil treated at seedling stage decreased with increasing sea water concentration (Fig. 11). Basil tolerated sea water application of 20% as seedling height was almost similar with treatments of 0 and 10% sea water. At 5 weeks after planting, seedlings treated with 40 and 80% sea water were shorter than seedlings treated at lower concentrations. At seedling stage, plant/root fresh and dry weights also decreased linearly with increasing concentration of sea water (Table 5). Tolerance threshold appears to be at 20% sea water for the parameters measured. Above 20% sea water, fresh and dry weights decreased drastically. A significant quadratic response was observed in the final soil salinity as a result of increasing concentration of sea water application (Fig. 12). The sharp increase in soil EC was noted from 10% to 40% sea water. A slight increase was observed from 40% to 80% and there was a tendency for soil EC to decrease at higher concentrations.

Basil - Flowering Stage

At flowering stage, sea water applications had no significant effect on basil plant height (Table 6). This indicates that basil can tolerate sea water application up to 80% with no siginficant reduction in plant height. However, at higher sea water concentrations, development of side branches

or shoots was suppressed. Plants have the tendency to grow vertically with no lateral shoots. Sea water application significantly reduced basil plant fresh and dry weights (Table 7). Tolerance threshold appears to be at 40% sea water. Root fresh and dry weights, however, were not affected by sea water application although there was a tendency for fresh and dry weights to decrease with increasing sea water concentrations (Table 7). As with experiment at seedling stage, a quadratic response was observed in the final soil salinity with increasing concentration of sea water application (Fig. 13). Similar response was measured and may indicate that application of saline water to basil will result in a rapid rate of soil salinization.

SUMMARY AND CONCLUSIONS

The study has established sea water tolerance thresholds for tomato, pepper and basil at seedling and flowering stages in terms of plant height, plant fresh and dry weights, root fresh and dry weights,and flower and fruit development. In all experiments, a significant linear or quadratic response was observed between sea water concentration and soil salinity. For tomato seedlings, tolerance threshold was established at 20% (13.7 dS/m) sea water. At flowering stage, application of 40% (25.8 dS/m) sea water resulted in a significant decrease of plant height, fresh and dry weights. Roots were sensitive to sea water application of 20%. In terms of plant fresh and drwy weights, tomato can tolerate sea water concentration up to 20% at flowering stage. Sea water concentration did not affect tomto flower and fruit development, however, optimum flower development was observed at sea water application of 20%.

Pepper seedling height was not affected by sea waer applications at various concentrations, but in terms of plant fresh and dry weights, tolerance level was established at 20% (13.7 dS/m) sea water. Roots were insensitive to the effect of sea water application as fresh and dry weights remained constant with increasing concentrations. At flowering stage, pepper plants tolerated application of sea water up to 40% (25.8 dS/m). At this concentration, plant height, fresh and dry weights were almost similar with those observed in treatments at lower concentrations. The tolerance threshold for root fresh and dry weights, however, was observed at 20% sea water application.

Basil tolerated sea water application of 20% at seedling stage in terms of plant height, fresh and dry weight. At flowering stage, sea water had no effect on basil plant height, however, at higher sea water concentrations, development of side branches was suppressed. For plant fresh and dry weights, tolerance threshold appeared to be at 40% sea water. As with plant height, root fresh and dry weights were not affected by sea water applications at various concentrations.

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Table 1. Effect of Sea Water on Tomato Flower and Fruit Development. UVI/AES, 1994

Sea Water (%)	Flowers (no./plt)	Fruits (no/plt)	Fruit Fresh Wt. (g)	Fruit Dry Wt. (g)
0	6.6	1.8	87.5	21.1
10	6.2	2.6	63.8	19 6
20	9.8	2.8	62.1	21.6
40	5.4	2.4	51.1	12 3
80	1.4	2 4	37 8	14 9
Linear	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS

NS=not significant

Table 2. Effect of Sea Water on Pepper Plant/Root Fresh and Dry Weights. UVI/AES, 1994.

Sea Water (%)	Plant		Root	
	F.W. (g)	D W. (g)	F.W (g)	D.W. (g)
0	7.26	1.68	0.62	0.18
10	6.94	1.58	0.53	0.16
20	6.29	1 13	0.69	0.26
40	5.36	0 79	0.32	0.09
80	3.41	0.72	0.36	0.12
Linear	*	**	NS	NS
Quadratic	NS	NS	NS	NS

Significant; **Highly significant; NS=not significant
F.W.=fresh weight; D.W.=dry weight

Table 3 Effect of Sea Water on Pepper Plant Height at Flowering Stage UVI/AES, 1994

Sea Water (%)	Weeks After Planting				
	1	2	3	4	5
	Plant height (cm)				
0	24.3	27.0	28.2	29.8	29.8
10	20.2	24.8	24.8	25.2	23.0
20	18.6	21.8	21.8	22.0	21.0
40	20.0	22.2	22.0	22.2	19.8
80	19.0	19.4	0.0	0.0	0.0
Linear	**	**	**	**	**
Quadratic	*	*	NS	NS	NS

*Significant (P<0.05); **Highly significan (P<0.01), NS=not significant

Table 4. Effect of Sea Water on Pepper Plant/Root/Fruit Fresh and Dry Weights UVI/AES, 1994

Sea Water (%)	Plant		Root		Fruit	
	F.W. (g)	D.W. (g)	F.W. (g)	D.W. (g)	F.W. (g)	D.W. (g)
0	17.5	5.92	7.38	2.69	43.6	5.53
10	18.8	4.54	4.32	2.53	23.1	3.29
20	15.1	3.55	3.33	1.75	24.8	3.67
40	6.4	2.88	1.79	1.38	5.8	1.14
80	2.1	1.38	0.37	0.70	0.0	0.0
Linear	**	**	**	**	**	**
Quadratic	NS	NS	**	NS	NS	NS

**Highly significant (P<0.01); NS=not significant

Table 5 Effect of Sea Water on Basil Plant/Root Fresh and Dry Weights at Seedling Stage, UVI/AES, 1994

Sea Water (%)	Plant		Root	
	F.W (g)	D.W. (g)	F.W (g)	D.W. (g)
0	18.3	2.60	1.94	0.43
10	18.4	2.37	2.92	0.48
20	15.9	2.22	2.75	0.46
40	8.0	1.05	1.24	0.22
80	7.8	1.22	1.22	0.26
Linear	**	**	**	**
Quadranc	NS	NS	NS	NS

**Highly significant (P<0.01); NS=not significant

Table 6. Plant height of Basil as Influenced by Sea Water Application at Flowering Stage. UVI/AES, 1994

Sea Water (%)	Weeks After Planting				
	1	2	3	4	5
	Plant height, cm				
0	32.4	45.9	55.2	66.2	69.0
10	28.5	46.1	62.2	72.8	76.2
20	29.0	43.9	52.0	59.0	60.2
40	29.2	52.8	58.4	61.8	63.0
80	25.2	48.6	56.0	61.2	61.8
Linear	NS	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS	NS

NS=not significant

Table 7. Effect of Sea Water Application at Flowering Stage on Basil Plant/Root Fresh and Dry Weights. UVI/AES, 1994.

Sea Water (%)	Plant		Root	
	F.W. (g)	D.W. (g)	F.W. (g)	D.W. (g)
0	49.2	7.64	5.09	1.77
10	47.9	8.40	5.62	1.66
20	31.5	6.19	3.46	1.16
40	29.7	6.71	3.00	0.99
80	15.9	3.65	2.47	0.87
Linear	**	*	NS	NS
Quadratic	NS	NS	NS	NS

*Significant (P<0.05); **Highly significant (P<0.01); NS=not significant

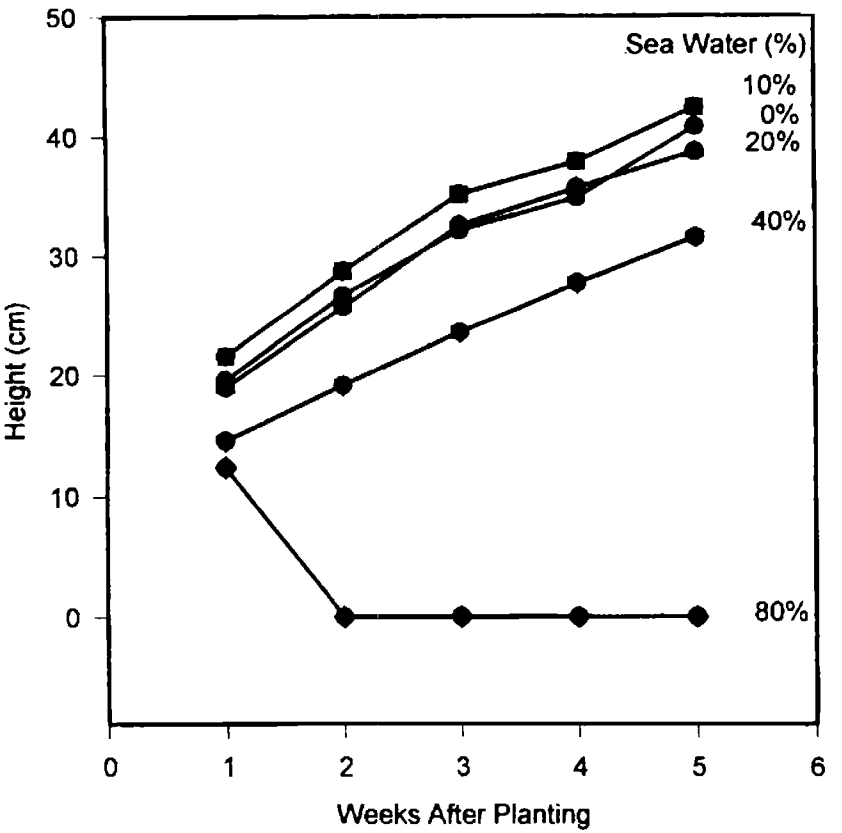

Fig. 1. Height of tomato seedlings treated with sea water.

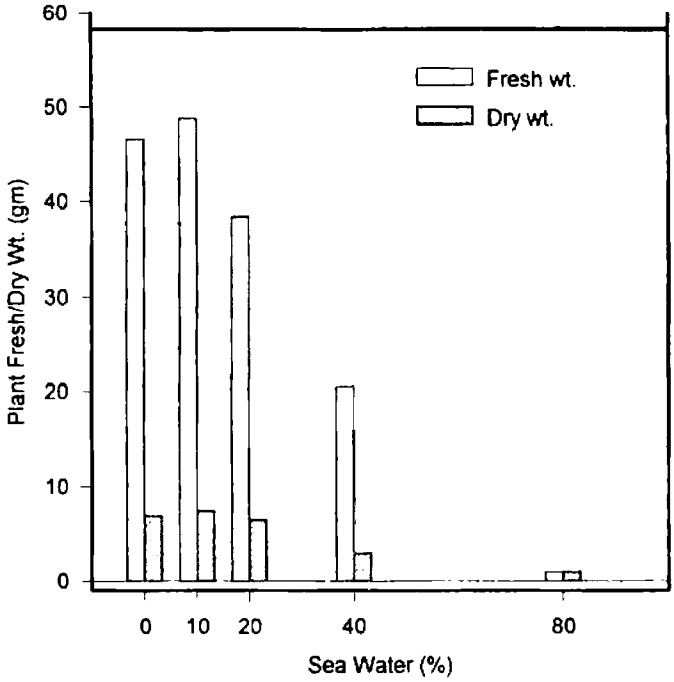

Fig. 2. Sea water effect on tomato seedling weight.

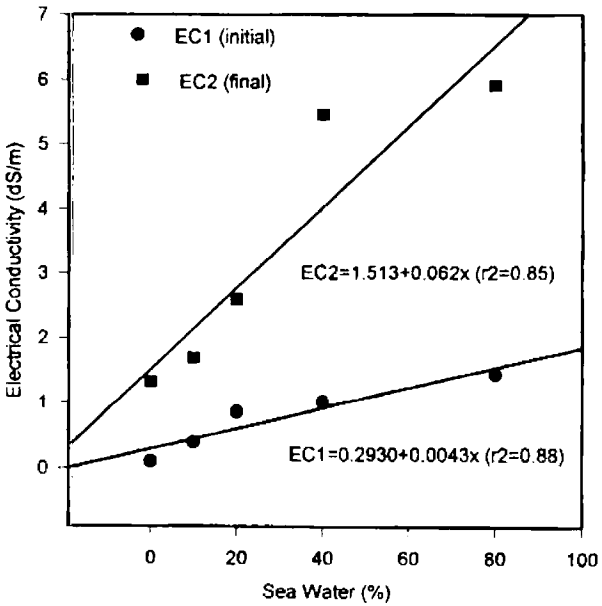

Fig. 3. Relationship between sea water applied on tomato seedling and soil salinity.

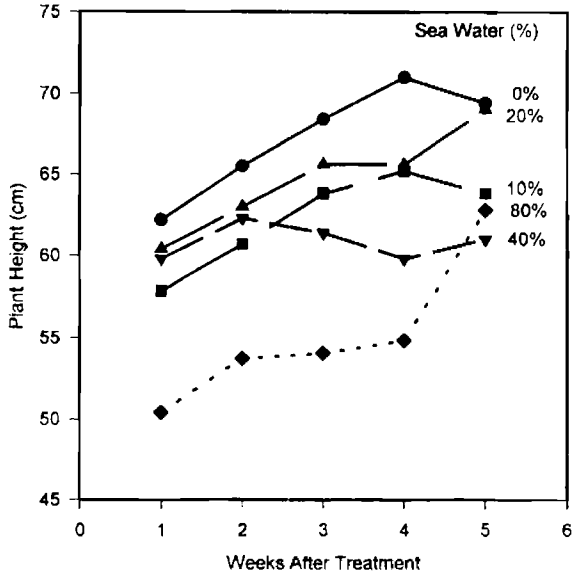

Fig. 4. Height of tomato treated with sea water at flowering stage.

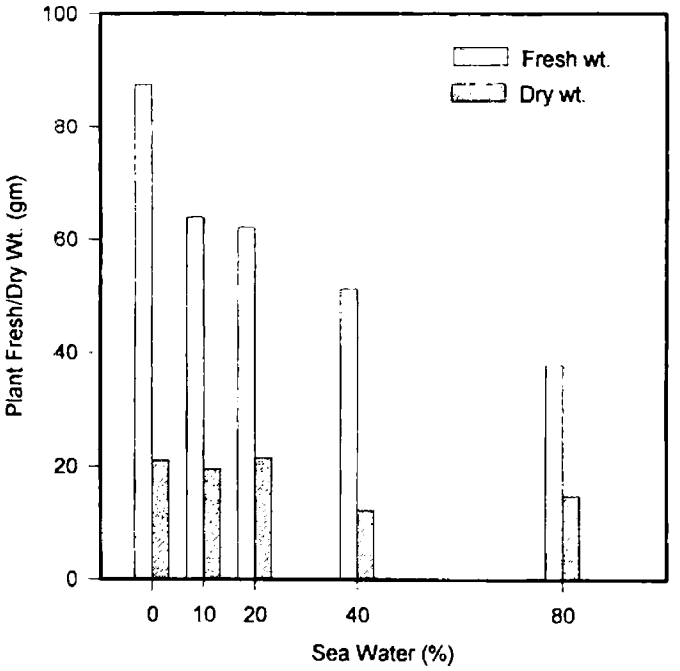

Fig. 5. Sea water effect on tomato plant weight.

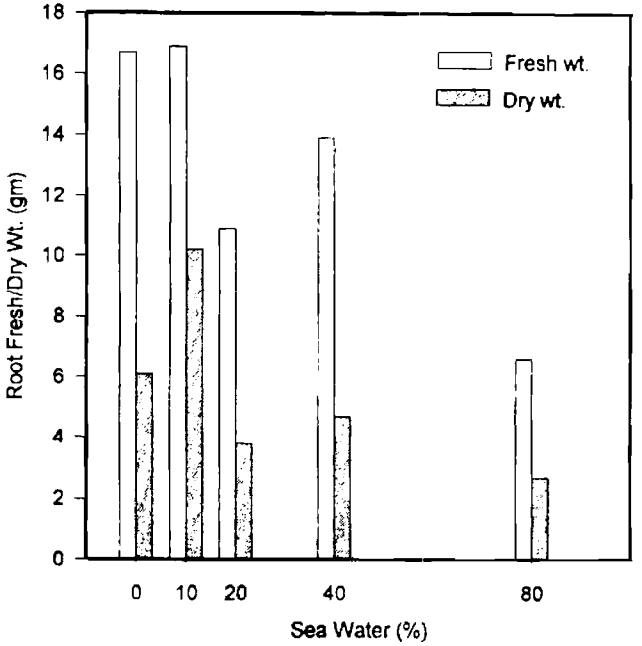

Fig. 6. Sea water effect on tomato root weight.

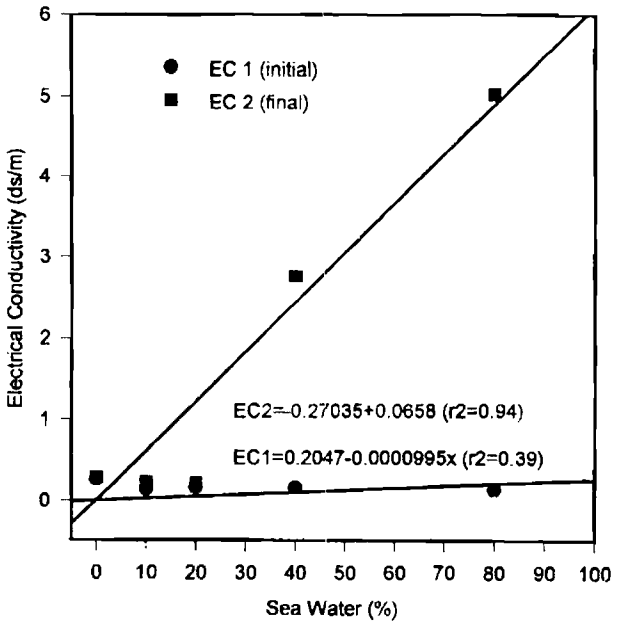

Fig. 7. Relationship between sea water applied on tomato and soil salinity.

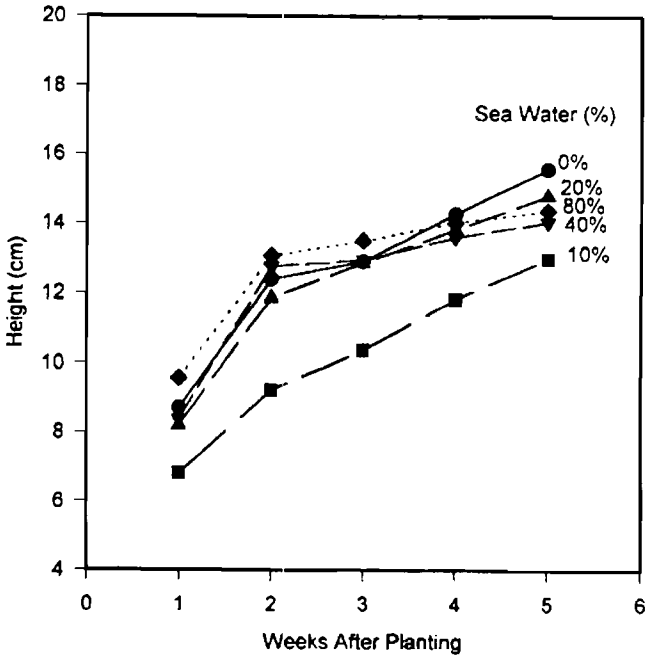

Fig. 8. Height of pepper seedlings treated with sea water.

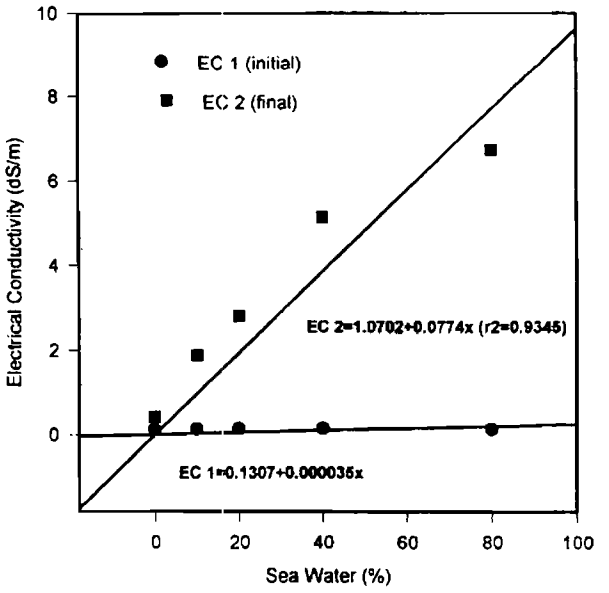

Fig. 9. Relationship between sea water applied to pepper seedling and soil salinity.

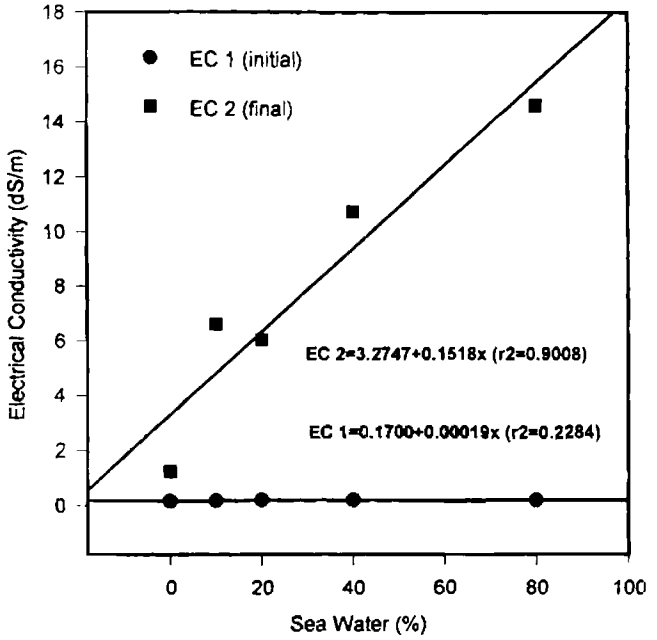

Fig. 10. Relationship between sea water applied and soil salinity (pepper).

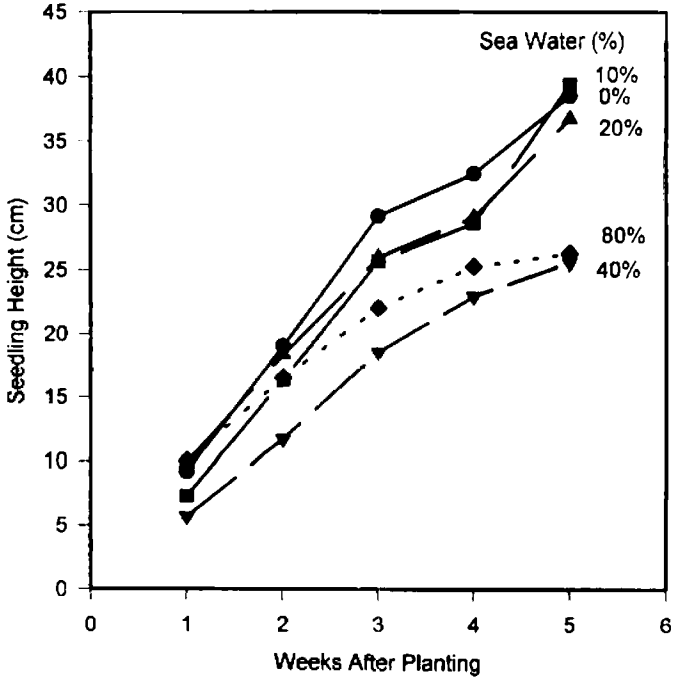

Fig. 11. Height of basil seedlings treated with sea water.

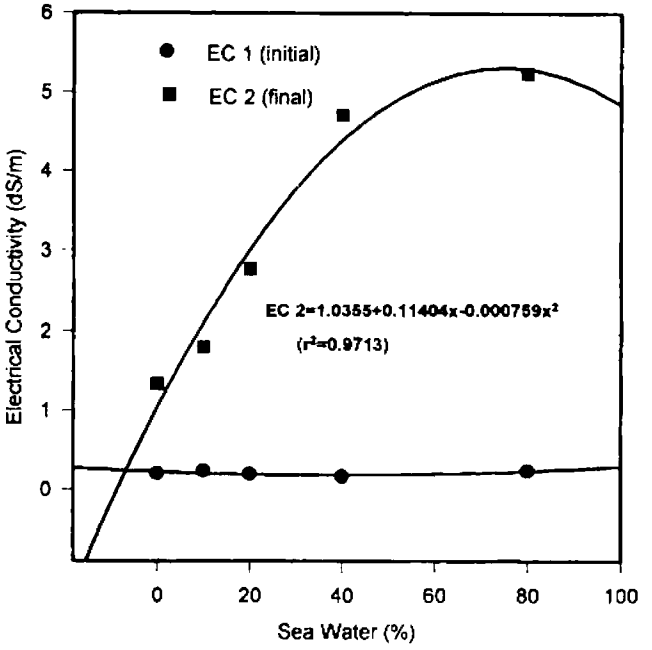

Fig. 12. Effect of sea water on soil salinity (basil seedling).

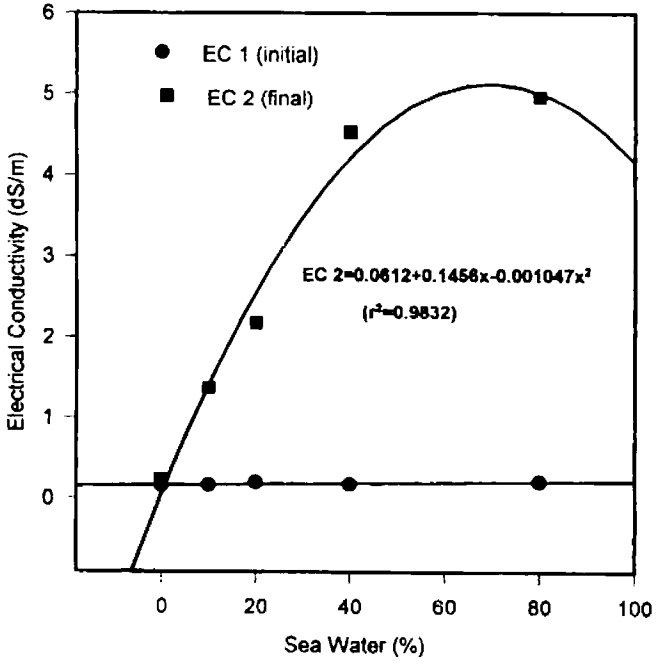

Fig. 13. Sea water effect on soil salinity (basil rep. stage).

PAST AND CURRENT IPM STRATEGIES TO COMBAT THE SPREAD OF *DIAPREPES ABBREVIATUS* (L.) IN FLORIDA CITRUS

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ABSTRACT

During the past 30 years, the West Indian sugarcane rootstalk borer weevil, Diaprepes abbreviatus (L.) has spread from its original site of introduction to 15 counties throughout the Florida citrus industry where it is considered a major long-term threat. Approximately 25,000 acres of citrus have confirmed infestations of the weevil. Most of the infested acreage is exhibiting severe decline or is out of production. Currently, control methods for the larvae are limited and chemical control for the adults appears to be only partially effective in severely infested groves and threatens current IPM strategies. At this time, biological controls have had limited success.

INTRODUCTION

Several species of curculionid weevils representing 11 genera have been reported from citrus and other host plants in the Caribbean region (Fig. 1). The literature suggests that many of the genera are indigenous to the Lesser Antilles but have spread to other regions of the Caribbean over time (O'Brien and Wibmer 1982, Woodruff 1985). Most species have a wide range of host plants and different species within most of the genera can be found coexisting on citrus in many regions. From an economic standpoint, species within the genera Exophthalmus and Diaprepes, appear to be most important. However, injury and economic thresholds for species within these genera are unknown for both citrus and sugarcane.

Nineteen species of Diaprepes are currently recognized; 17 of West Indian origin (Woodruff 1985). D. abbreviatus (L.) and D. famelicus (Olivier) are considered the most destructive species to citrus and sugarcane (Whitwell 1990). The latter species appears to be confined to the Lesser Antilles but can be found with D. abbreviatus on the same host plant. On the other hand, D. abbreviatus has a widespread distribution within the Caribbean region but interestingly is not found in Jamaica (Fig. 1). It was first reported as a destructive pest of sugarcane in the West Indies around the turn of the century (Watson 1904). Numerous reports of severe larval injury to the root system of both citrus and sugarcane grown in the West Indies have been made by entomologists throughout this century. Both biological and chemical methods have been devised for larval and adult control (Wolcott 1936, Fennah 1942, Martorell and Gaud 1965, Mauleon and Madembe-Sy 1988). In the Dominican Republic, Martinique and other regions where citrus and sugarcane appear as mixed plantings in calcareous soils, larval feeding by Diaprepes spp. can be devastating to a grove. During the last 5 years, I have observed gradual decline and finally total destruction of a young citrus planting located adjacent to sugarcane in the La Romana region of the Dominican Republic. This destruction has occured even though both contemporary chemical and biological control methods against adults and larvae were applied as a regular management strategy. During peak adult emergence from sugarcane and citrus, as many as 100 adult D. abbreviatus were counted on a given citrus tree.

The sugarcane rootstalk borer weevil was first reported in Florida in 1964 in an ornamental

nursery in Orange County near Apopka, Florida (Woodruff 1964). Since ornamental plants known to be hosts for Diaprepes were being imported into the USA from Puerto Rico, it is suspected that either immature and/or adult stages could have entered Florida undetected on ornamentals from that area. The purpose of this paper is to present a historical overview on the dispersal of D. abbreviatus throughout Florida since its introduction 30 years ago and to discuss various control strategies that are currently being used and others that are under development to combat this major pest of the Florida citrus industry.

DISPERSAL OF Diaprepes abbreviatus THROUGHOUT THE FLORIDA CITRUS INDUSTRY: A CASE HISTORY

Following its fortuitous introduction in 1964, 4 years passed before D. abbreviatus was detected again in the same citrus nursery (Jones 1969). A larva was recovered from damaged roots of a containerized plant. Further surveys within the immediate area produced a number of adults confirming establishment of the weevil. Within a few days, State and Federal regulatory agencies intensified their survey within the area which led to the definition of 8,000 acres in Orange County requiring immediate quarantine. Shortly thereafter, 70% of the regulated area, which included commercial citrus, received soil treatment for control of larvae using granular heptachlor or dieldrin. Subsequently, foliar chemical sprays with Sevin (carbaryl) for adult eradication were initiated in an attempt to eliminate the weevil. Within months after eradication was initiated, the use of the above chlorinated hydrocarbons was terminated at the request of the Federal government. Foliar spraying at 10 day intervals was continued thereafter, but was doomed to failure because of factors such as adult reinfestation fromalternate host plants, short residual of foliar chemical treatments and simply the inefficiency of the aerial sprays. Subsequently, soil-applied heptachlor and chlordane were used to control larvae of D. abbreviatus until their use was canceled in 1979.

In 1974 and 1975, the weevil was detected for the first time in Broward and Dade Counties, respectively (Fig. 2). It is unknown whether these new findings represented new introductions from the Caribbean or were the result of movement of plant material from Orange County. According to Griffith (1975), the regulated area in Orange County was now 32,640 acres. This area included 3,903 acres of infested commercial citrus and 113 infested ornamental nurseries. By 1980, the weevil had spread to the adjacent counties of Lake and Seminole and hopes for containment were virtually gone (Fig. 2). Then, in 1982 and 1983, catastrophic freezes destroyed greater than 80% of the commercial citrus acreage in Orange, Lake and Seminole Counties including most of the acreage infested with Diaprepes. The importance of the weevil declined significantly as the citrus industry began its recovery with an exodus to the noninfested southwestern region of the state.

Diaprepes survived the devastating freezes and was reported again in the Indian River area at Fort Pierce and in Polk County near Alturas in 1984 and 1986, respectively. However, its reemergence and continued dispersal was hardly noticed in the mid-eighties when the eradication of citrus canker received priority attention in citrus production. In 1984, use of Lorsban (chlorpyrifos) as a soil treatment for larvae was canceled by the manufacturer and chemical controls for larvae were reduced to zero. Within the last 4 years, Diaprepes has been detected in 7 new counties including newer plantings in Collier, Hendry and Glades Counties (Fig. 2), completing its dispersal to all major citrus growing areas of the state. Weevils discovered in the Moore Haven area in an ornamental nursery in 1993 place the pest within the northwestern edge of the sugarcane growing area in Glades County.

CURRENT IPM STRATEGIES FOR THE CONTROL OF LARVAL AND ADULTS OF Diaprepes abbreviatus

During the past 25 years, numerous biological and chemical control methods have been evalu-

ated by Federal and State agencies for each developmental stage of Diaprepes in Florida. In many instances, these research programs were designed after earlier work done by entomologists in the West Indies or they involved joint cooperation among scientists through the Caribbean Basin Administrative Group (CBAG) and other support agencies. In addition, environmental regulation has impacted significantly on the utilization of research on chemical and microbial methods, particularly asrelated to larval control and no doubt will continue to do so in the future. As the following review of past and current applied research will clarify, future research must be conducted in an IPM context where we use both nonchemical and chemical methods judiciously, but guarantee the grower acceptable crop protection. The major research effort must focus on the control of the developmental stage or stages that have a direct impact on the host plant. Since there is no published scientific information available on the economic impact of the different developmental stages of D. abbreviatus and such data is very difficult to generate, presently, we must speculate on this matter in view of the seriousness of the problem.

Biology and Control Strategies for the Adult Stage

In Florida, highest adult emergence by D. abbreviatus occurs from May through October with peak emergence either in June or September (Beavers and Selhime 1976). By comparison, highest adult emergence occurs from March through June in the West Indies (Wolcott 1934). Adults live for several months and never return to the soil from which they emerge. Adults prefer to rest on shaded interior foliage of a citrus tree canopy during full sun; however, they aggregate on the new leaf flush in subdued light to feed, mate and oviposit. Leaf feeding by high populations of adult Diaprepes can be so severe that new flushes formed during the summer and fall are totally consumed.

Both invertebrate and vertebrate predators are known to feed on adult weevils during the arboreal time of their life cycle. Specifically, toads, birds and spiders have been observed preying on adults (Tucker 1940, Whetmore 1916, Whitcomb et al. 1982), however, the importance of adult predation is unknown and attempts have not been made to augment predator populations in the field through environmental manipulation.

The entomopathogenic fungi, Beauveria bassiana and Metarhizium anisopliae, are pathogenic to adult weevils (Wolcott 1952, Beavers et al. 1983). Adults can come in contact with these fungi during their exodus from the soil or through contact on the plant surface. When these fungi are applied as a foliar spray (Bullock et al. 1988) or to the soil surface beneath the tree canopy (McCoy 1989) at high conidial concentrations ($> 1 \times 10^6$), adult weevil mycosis has been increased on both substrates. Although no reports of adult Diaprepes parasitism by entomogenous nematodes were found in the literature, there is a high probability of it occurring in the soil.

Chemical control of adult D. abbreviatus using foliar sprays applied during peak emergence are recommended to suppress adult populations, thereby reducing the number ofgravid females, egg deposition and larval entry into the soil (Bullock et al. 1988, Futch and McCoy 1994). Numerous pesticides are available to citrus growers for adult control (Knapp 1994); however, many have limitations and none of the products have greater than 4 weeks residual activity, even when applied with a necessary low rate of petroleum oil. Therefore, more than one application usually will be required during the adult emergence period. Since multiple pesticide applications can interfere with the efficacy of natural enemies and/or lead to resistance, foliar sprays for adult control are discouraged and should be used only in groves where Diaprepes is severe.

Biology and Control Strategies for the Egg Stage

Adult female D. abbreviatus lay eggs in clusters between leaves stuck together with an adhesive substance produced by the female. Oviposition begins 3 to 7 days after adult emergence from the soil and continues daily for several months. The number of eggs per cluster varies from 30 to 264

and a single female may lay more than 5,000 eggs during her lifetime (Wolcott 1936, Woodruff 1968). Eggs hatch almost uniformly in 7 days; hatch averages about 90% at 28°C in the laboratory (Beavers 1982).

A number of egg parasitoids of D. abbreviatus have been reported from the Caribbean region (Schauf 1987, Delvare 1988, Etienne et al. 1991, Etienne et al. 1992). Three eulophids, Aprostocetus (=Tetrastichus haitiensis (Gahan), A. gala (Walker), and Baryscapus fennahi (Schauff), as well as the trichogrammatids, Ceratogramma etiennei Delvare and Brachyufens osborni (Dozier) appear to be most widespread. Only three hymenopterous parasites have been reported attacking the egg stage of D. abbreviatus in Florida, namely A. (=Tetrastichus) haitiensis, B. osborni and an unidentified trichogrammatid (Beavers et al. 1980). Virtually nothing is known about the population dynamics of these egg parasitoids and how foliar pesticides effect their abundance and distribution from grove to grove.

From 1969 to 1972, T. haitiensis was introduced from Puerto Rico for the classical biological control of D. abbreviatus (Beavers et al. 1980, Beavers and Selhime 1976); however, only dead parasites were recovered from parasitized eggs. Recovery of only dead parasites from parasitized weevil eggs suggests effective host defense or lack of host specificity and the need for further introductions of different biotypes of the same species. Therefore, further classical biological control could improve overall natural control of eggs thereby reducing the larval population entering the soil. Researchers should be aware; however, that hyperparasites of Aprostocetus do occur in the West Indies (Schauff 1987).

Ants and spiders are known to prey on the eggs of D. abbreviatus. In studies conducted by Richman et al. (1986) in Florida and Puerto Rico, the ant species, Monomorium floricola (Jerdon) and Crematogaster ashmeadi Mayr, were observed consuming egg masses during the spring and summer.

Two chemical control strategies have been proposed for increasing mortality of the egg stage of Diaprepes. The first strategy involves the use of petroleum oil as a foliar spray, which appears to weaken the bonding characteristics of the adhesive substance responsible for the attachment of the eggs to leaf or leaf to leaf (Schroeder et al. 1977). By altering the natural protection afforded by the folded leaf, egg mortality is increased via physical exposure and predation.

For years, oil sprays have been widely used in the summer during the weevil oviposition period for the control of greasy spot disease and phytophagous invertebrates of Florida citrus, so its benefits for Diaprepes egg suppression are being realized to some extent.

Insect growth regulators (IGR) such as Micromite (diflubenzuron) offer a second strategy. This acaricide has a Federal registration pending for control of the citrus rust mite and citrus leafminer in Florida citrus and state approval for use as a ovicide against Diaprepes on nonbearing citrus. When this IGR is applied with petroleum oil to the tree, it reduced the reproductive potential and egg viability of female D. abbreviatus exposed to treated leaf flush in the field (Schroeder et al. 1976, Schroeder and Sutton 1978). Since Micromite is not toxic to the adults, spray coverage and residual activity on the leaves during the summer will be critical to field performance or its use can be combined with a foliar adulticide.

Biology and Control Strategies for the Larval and Pupal Stage

After one week, the neonatal larvae of D. abbreviatus hatch from the egg and fall to the soil surface beneath the tree. Generally, they remain active on the soil surface for a few hours before entering the soil (Jones and Schroeder 1983). At this time, they appear to be most vulnerable to predators (Whitcomb et al. 1982) and surface applied pesticides. As neonate larvae age, their ability to enter the soil increases. Larvae cannot enter dry soil (< 2% soil moisture). Once in the soil, it is assumed that the larvae feed initially on the smaller fibrous roots of citrus and subsequently move to the lateral roots. The number of larval instars completed in the soil is highly variable; Wolcott (1934) suggested 8 instars before the onset of the inactive period before pupation.

The late instar active larvae are particularly injurious to the crown area of the tree where they literally strip away the cortical layer. Larvae canremain partially inactive for up to a year (Woodruff 1968). The whole larval period lasts from 250-350 days in the Caribbean and Florida. Prior to pupation, a vertical chamber is formed in the soil in which the larvae compacts the soil by spinning on its caudal end. This chamber appears to protect the pupae from natural enemies and physical factors. Pupation occurs within 15-20 days after the chamber is formed. Adults exiting the pupal chamber remain in the soil for up to 120 days before moving to the surface.

Although there are no known parasites of the larval stage of D. abbreviatus, numerous species of ants and earwigs that forage on the surface of the soil have been reported as predators (Whitcomb et al. 1982, Tryon 1986). However, the efficacy of these predators is unknown. Earwigs were found to forage only at night and ants ceased to forage after rains. Recent studies by Jaffe et al. (1990) and Whitwell (1990) showed that ants were repelled by the neonatal larvae. Further research showed that neonatal larvae produce a defensive secretion identified as a sesquiterpene that repelled the fire ant, Solenopsis geminata (F) (Pavis et al. 1992). Novel methods of environmental manipulation are needed to enhance arthropod predation on the larvae.

The soil contains a number of entomopathogenic fungi and entomogenous nematodes that attack the larval stage of various soil insects. The fungi, B. bassiana, M. anisopliae, Paecilomyces lilacinus and Aspergillus ochreaceous in descending order of occurrence were isolated from Diaprepes larvae in Florida soils (Beavers et al. 1983). In addition, nematodes of the genera Heterorhabditis and Steinernema have been found infecting larvae of D. abbreviatus throughout the Caribbean region (Beavers et al. 1983, Roman and Beavers 1982). Fungi and nematodes appear to be most prevalent in citrus soils from June through August in Florida; however, the distribution and abundance of these organisms is variable because of many interacting physical and biological antagonists that occur in all natural soils. As research improves our understanding of entomogenous fungi and nematodes in natural soils, practical ways to manipulate and/or augment soil conditions in favor of the survival and proliferation of these natural enemies may lead to better biological control.

Currently, considerable attention is being given to the development of both nematodes and fungi as microbial control agents of D. abbreviatus larvae throughout the Caribbean region. In Florida, focus is on the use of fungi for the control of neonatal larvae on the soil surface (McCoy et al. 1984, McCoy 1991) and nematodes for the control of larvae beyond the first instar in the soil rhizosphere (Schroeder 1990, Schroeder 1992). Preliminary data show that fungal conidia will attach to the nematode cuticle, and therefore, can be transported in soil without infecting the nematode(McCoy 1991), suggesting that these pathogens can co-exist in tropical soils without negatively affecting each other.

Current research and field observations suggest that both pathogens are limited by numerous environmental factors that affect their reliability as biopesticides, and no research data are available as to how their performance protects the root system of the tree in time. Likewise, neither pathogen appears effective in achieving the high level of control (virtually 100%) needed for containerized plants in citrus and ornamental nurseries (Schroeder 1987). However, laboratory and field studies currently underway show that two nematodes, S. riobravis and H. bacteriophora, are more efficacious than commercially produced S. carpocapsae. Although encouraging, it remains to be seen whether more effective species or strains of nematodes can give reliable plant protection from Diaprepes under Florida conditions.

In the case of fungi, virulent isolates of B. bassiana (McCoy and Boucias 1989) and M. anisopliae (Storey et al. 1990) have been selected for D. abbreviatus and have been applied to citrus soils as conidial and mycelial preparations, respectively. In field tests where B. bassiana has been applied as a conidial powder at practical rates (18-20 lb/treated acre), the fungal conidial density was always increased by 3 to 4 logs compared to the control but persistence in the surface soil has varied from 4 to 10 wk post-treatment (McCoy 1989). Larval mycosis in treated soil has varied from 60 to 80% shortly after treatment but then declined (McCoy 1989, McCoy, unpublished data). In the case of M. anisopliae, mycelial granules applied at 5 g/m^2 give similar results; however, the cost of

fungal production at this use rate exceeds $1000 per acre (Schwarz 1994). Further field studies are needed to determine if Beauveria can achieve reliable control of neonatal larvae at the soil surface to adequately protect the root system of the tree. Laboratory research is currently addressing the use of sublethal doses of certain pesticides and bacteria in combination with fungi for neonatal larval control.

There are no chemical pesticides currently available for controlling the larvae in the soil in either nurseries or the field. Currently, there are 3 compounds that are giving encouraging results. SuScon Green, a slow release polymer granule containing 10% chlorpyrifos, when incorporated into citrus potting mix and Candler soil has been effective in killing 100% of the neonatal larvae placed in containers each month for 7 months. However, when the product is broadcast on the soil surface, it is less effective. A registration for use in citrus nurseries is being pursued. Admire 2F (imidicloprid) has been effective as a soil drench for the control of neonatal larvae in greenhouse studies. The compound is systemic in the citrus plant and, although the larvae appear intoxicated in the soil, data suggest thatmortality occurs when larvae begin feeding on the fibrous roots.

Admire is currently registered as a soil treatment for citrus leafminer in Florida. Talstar 10WP and Capture 2EC (bifenthrin) are being tested both in the field and greenhouse against all stages of Diaprepes larvae. Preliminary studies show that this synthetic pyrethroid is active at 5 ppm or greater on neonatal larvae. A temporary registration (Section 24c) for use of Talstar in citrus and ornamental nurseries is pending. Field studies with Admire and Capture are under way.

CURRENT STATUS OF THE PROBLEM IN FLORIDA

Although total citrus acreage infested with D. abbreviatus appears very low (< 25,000 acres) in Florida based on a 1993 survey conducted by the Florida Department of Agriculture, the potential for further spread to citrus and sugarcane is tremendous in view of the fact that it is established in virtually all growing regions in the state and control methods are currently limited. It should be pointed out that current adult visual detection methods are insensitive and the infested acreage is most likely greater than the above estimate. Citrus growers with Diaprepes in their groves are experiencing major crop loss through severe tree decline and mortality. The pest is already a major problem to the ornamental industry in view of the number of infested nurseries and the lack of controls for the weevil. In addition, infested citrus and ornamental nurseries are a potential source for spreading the weevil via the sale of infested containerized and to a lesser extent bare rooted plants.

Because of the increased concern over the spread of D. abbreviatus and its devastating effect on the citrus tree in Florida during the past year, a grower-initiated Task Force was organized under the leadership of Mr. J. B. Pratt, Polk County citrus grower, and Ms. Connie Rieherd of the Florida Department of Agriculture and Consumer Services. This 27 member Task Force has as primary objectives: 1) establishment of a grower awareness program within the citrus industry to combat the spread of Diaprepes and 2) encourage both short- and long-term strategies for control of this pest through research and extension programs. The Task Force supports international development in any areas of agriculture that will lead to a solution to this devastating problem both in Florida and throughout the Caribbean region.

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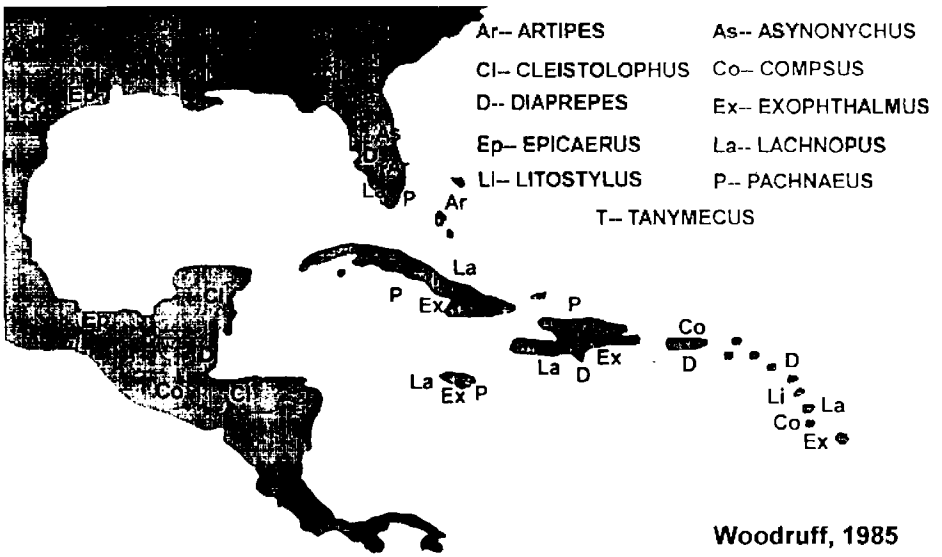

Fig. 1. Major Genera of the Curculionidae important to Citrus in the Caribbean Region.

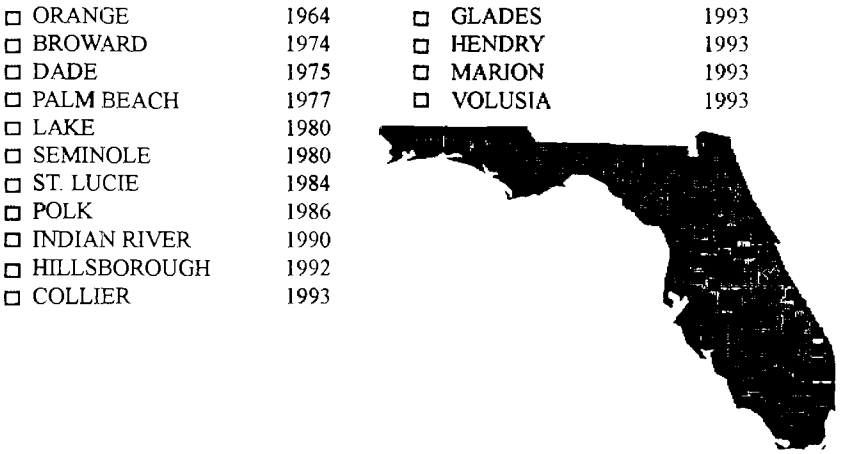

Fig. 2. Infestation by *Diaprepes* of Florida Counties by Year.

INDICATORS OF RESISTANCE IN COCOA (*THEOBROMA CACAO*) TO BLACK POD DISEASE CAUSED BY *PHYTOPHTHORA PALMIVORA*

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ABSTRACT

The relationship between morphological characteristics: stomatal frequency, stomatal pore length, surface wax, hardness of pod wall and pod susceptibility to *P.palmivora* infection was assessed in twelve selected cocoa clones of the Forastero and Trinitario types. Among these clones, significant variation was observed with respect to pod morphological characteristics and their responses to infection. A high positive correlation was obtained between the combined effect of stomatal frequency and pore length, and clonal susceptibility. This suggests that these two morphological characteristics together could be used as a selection criterion for the identification of resistant genotypes.

INTRODUCTION

Black pod disease of cocoa caused by *Phytophthora palmivora* occurs in all cocoa-growing areas and accounts for more loss of crop than any other single disease of cocoa (Spence, 1961; Prendergast and Spence, 1967). Globally, about 20 to 30 per cent of the world crop is lost annually due to *Phytophthora* infection (Opeke and Gorenz, 1974). Losses at some locations could, however, increase to about 95 per cent, depending on weather conditions and the inherent resistance of cocoa cultivars (Tollenaar, 1958; Opeke and Gorenz, 1974; Lass, 1985). Several copper-based fungicides are being used by farmers to control the disease, but this method is expensive and not completely effective (Lass, 1985). The use of genetic resistance seems cheaper in the long run, but this will require effective selection criteria for the identification of resistant genotypes.

At present, the search for varieties with desirable resistance has been difficult due to lack of selection criteria. Although, some useful information could be obtained from the incidence of diseased pods, which is often used for selection; such results are often influenced by changes in weather conditions, the amount of inoculum within the field, number of pods per tree, and possible escape from infection (Amponsah, 1987). Similarly, the identification of resistant genotypes using certain inoculation techniques have been inconsistent, thus limiting the chances of selecting the most resistant variety. To overcome these problems, this study investigates the relationship between varietal resistance and pod morphological characteristics with the intention of using those characters with high correlation as selection criteria against the black pod disease of cocoa.

MATERIALS AND METHODS

Test plants and selection of sample

The clones selected were SCA 6, SCA 12, CATONGO, PA 30, PA 47, IMC 67, (Forasteros), ICS 1, ICS 6, ICS 8, ICS 40, ICS 84, and ICS 95 (Trinitarios). Mature unripe pods (same size

as ripe pods of the same clone) were used in the experiments.

Preparation of inoculum

Zoospore suspension was prepared from a ten day old culture of *P.palmivora* following the method of Lawrence (1978). The concentration of zoospore was determined using a haemocytometer and adjusted to 30,000 zoospores/ml. This concentration was found to discriminate best among clones of varying degrees of resistance in a preliminary experiment and was used for the inoculation experiment.

Inoculation and assessment of resistance

The multiple point inoculation technique was adopted, in which inoculation was effected along the two upper ridges on pod surface by placing a drop of inoculum (4il) at 10 points using a micro-pipette. A distance of about 3cm was maintained between inoculated points (5 points per ridge) to avoid merging of lesions. Inoculated pods were incubated at 100% relative humidity and 25°C in trays lined with moist tissue paper and covered with polythene film.

After 72 hours of incubation, the number of established infection points were recorded as a measure of pod resistance. An average of 17 pods were assessed per clone to determine the degree of resistance among the selected varieties.

Evaluation of pod morphological characteristics

The following morphological characteristics were evaluated to assess the variability among clones.

Stomatal frequency and pore length

By applying nail polish to the surface of cocoa pods, stomatal impressions were obtained and examined under an Olympus microscope. Stomata were counted within the field of view using x40 objective and pore lengths measured with an ocular micrometer.

Five points per pod in 15 pods were examined for each clone and the frequency of stomata was estimated as the number of stomata/mm^2 of pod area.

Pod surface wax

Surface wax was extracted by dipping the base of pod into chloroform for 20 seconds (Martin and Batt, 1958; Balasimha, et al. 1985). The extract was evaporated to dryness in a fume cupboard and the wax content determined gravimetrically per cm^2 of pod surface area. Ten pods per clone were assessed for their wax content.

Hardness of pod wall

The relative hardness of pod wall was determined using the Instron Universal Testing Instrument (Model 1130). A brass needle (3.1mm diameter) with a piercing angle of 30^0 and a load range of 0-20kg were used for the test. Data was converted to newtons (N) per mm^2. Ten pods per clone were assessed.

Data analysis

The data collected from the above experiments were subjected to the analysis of variance to assess the differences between genotypes. In addition, a correlation analysis was performed to determine the relationship between varietal resistance and pod morphological characteristics.

RESULTS AND DISCUSSION

Assessment of pod resistance

The mean number of infection points following laboratory inoculation of the selected clones are shown in Table 1. The analysis of variance showed a significant difference among the tested clones. However, the mean number of infection points produced on IMC 67, ICS 95, ICS 6, SCA 12 and CATONGO were not significantly different from each other. These varieties were noted to be more susceptible than the other clones. SCA 6, ICS 84 and ICS 1, on the other hand, showed a marked difference from other clones. The mean number of infection points were significantly lower in these clones. Other clones including PA 47, PA 30, ICS 8 and ICS 40 were moderately susceptible to infection.

The clones SCA 6, ICS 84 and ICS 1 showed a substantial degree of resistance to infection which could be exploited for the improvement of cocoa resistance to *P.palmivora*.

Assessment of pod morphological characteristics

The mean values for stomatal frequency and pore length, surface wax and relative hardness of pod wall for the selected clones are presented in Table 2.

The analysis of variance showed a significant difference among clones with respect to the four morphological characteristics that were assessed. The frequency of stomata, ranged among the clones tested, from 13.63/mm^2 in ICS 1 to 46.00/mm^2 in CATONGO. Fewer stomata were found in ICS 1, SCA 6, ICS 84 and ICS 8 (13.63 - 19.48/mm^2). In contrast, high stomatal frequency was observed among the other clones examined (24.52 - 46.00/mm^2). This variation in stomatal frequency, suggests that selection would be effective for this character among the clones.

Among the clones investigated, the stomatal pore lengths of ICS 95 and IMC 67 (13.70µm, 13.00µm) were greater than those of PA 30, SCA 6, PA 47 and ICS 48 (10.08µm, 10.25µm, 10.65µm and 10.97µm). The differences between CATONGO, ICS 1, ICS 6 and SCA 12 were not significant.

The differences in pod surface wax, ranged from 27.81µg/cm^2 in ICS 84 to 7.70µg/cm^2 in ICS 40 among the clones that were tested. The amount of wax extracted from CATONGO, IMC 67, SCA 12, SCA 6, ICS 40 and PA 30 were not significantly different from each other.

The relative hardness of pod wall also varied among the clones. A higher level of hardness was observed in IMC 67, ICS 40, CATONGO, ICS 84 and PA 30 in comparison to the other c ones with a lower level of hardness.

Correlation between the frequency of infection and pod morphological characteristics

High correlation values were obtained for lesion frequency vs stomatal frequency, and lesion frequency vs pore length (Table 3). However, a stronger relationship was obtained between the infection frequency and the combined effect of stomatal frequency and pore length ($r = 0.89$, P 0.05). These two factors complemented each other and their relationship with resistance appeared most outstanding (Table 3). The inclusion of the other parameters (surface wax and pod hardness) did not improve the correlation value ($r = 0.90$).

The clones SCA 6, ICS 84 and ICS 1 were found to be more resistant than the other clones and they possess the lowest stomatal frequency along with relatively shorter pore length. CATONGO, IMC 67, ICS 6, ICS 95 and SCA 12, on the other hand, were found to be susceptible and they showed a higher stomatal frequency and longer pore length. This result suggests that pod reaction to *P.palmivora* could be influenced by the number of stomata, as well as the size of the pore. Consequently, these two morphological characteristics can be used together as selection criterion for the identification of resistant genotypes for use in breeding programs.

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Table 1. Mean number of lesions (transformed values) produced on pods of 12 cocoa clones following inoculation with *P.palmivora*.

Clones	Mean number of lesions (transformed values)
CATONGO	2.95 (*7.79)
IMC 67	3.03 (*8.20)
SCA 6	2.53 (*5.45)
ICS 1	2.58 (*5.72)
ICS 6	3.01 (*8.11)
ICS 95	2.99 (*8.00)
PA 47	2.68 (*6.19)
PA 30	2.69 (*6.30)
ICS 40	2.64 (*6.00)
ICS 84	2.57 (*5.65)
ICS 8	2.64 (*6.00)
SCA 12	3.00 (*8.00)
LSD (0.05)	0.06

Data was transformed using, (x+1)
* Actual values

Table 2. Pod morphological characteristics of 12 cocoa clones.

Clones	Stomatal Frequency/ mm^2	Stomatal pore length (um)	Surface wax (ug/cm^2	Hardness of pod wall (N/mm^2)
CATONGO	46.00	11.57	7.76	5.26
IMC 67	33.78	13.00	8.26	7.52
SCA 6	15.93	10.25	8.82	4.37
ICS 1	13.63	11.40	10.06	4.25
ICS 6	36.30	11.50	13.60	4.55
ICS 95	29.63	13.70	10.65	4.70
PA 47	39.63	10.65	23.72	4.76
PA 30	32.67	10.08	8.12	5.21
ICS 40	24.52	12.23	7.70	5.41
ICS 84	19.19	10.97	27.81	5.22
ICS 8	19.48	12.30	10.04	4.31
SCA 12	38.00	11.87	8.22	4.20
LSD (0.05)	6.22	0.60	2.05	0.49

Table 3. Correlation between morphological characteristics and the frequency of lesions produced on pod surface.

Characters	r
Lesion frequency vs stomatal frequency	+0.73
Lesion frequency vs stomatal pore length	+0.58
Lesion frequency vs surface wax	- 0.31
Lesion frequency vs hardness of pod wall	+0.31
Lesion frequency vs stomatal frequency and pore length	+0.89
Lesion frequency vs stomatal frequency, stomatal pore length and surface wax	+0.90
Lesion frequency vs stomatal frequency, stomatal pore length, surface wax and hardness of pod wall	+0.90

TOWARDS AN INTEGRATED PEST MANAGEMENT PROGRAM FOR DIAMONDBACK MOTH IN BARBADOS

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ABSTRACT

On the basis of a survey of cabbage farmers' practices and studies of the level of insecticide resistance in diamondback moth in Barbados, a provisional integrated pest management program for diamondback moth has been devised. Those components that have been implemented are reviewed. Components that need to be added are discussed. Research needs, and research realities, are discussed in relation to keeping the program current.

INTRODUCTION

Diamondback moth [*Plutella xylostella*] is a major pest of brassicaceous crops, especially cabbage (*Brassica oleracea* var. *capitata*), wherever they are grown. In Barbados, the development of insecticide resistance in diamondback moth (Gibbs *et al.*, 1989; Gibbs and Chinnery, 1993; Chinnery *et al.*, 1993 and Gibbs, 1993), led to a decline in cabbage production (Fig. 1).

In addition to the environmental and human health consequences of the resultant excessive use of insecticides (Chinnery and Gibbs, 1990), reduced cabbage production led to the importation of diamondback moth infested cabbage from a country using outdated (banned/ineffective) insecticides, compounding the problem.

The results of a survey of the practices of 60 Barbadian cabbage farmers, carried out between September 1988 and June 1990 (Gibbs, 1993), were used to develop a provisional Integrated Pest Management (IPM) program for diamondback moth in Barbados.

THEORY

IPM involves all aspects of the crop cycle from site selection and land preparation to harvest.

Flint and van den Bosch (1983) listed three key aspects of the philosophy behind IPM systems:

(1) a conception of the managed resource as a component of a functioning ecosystem,
(2) an understanding that the presence of an organism of pestiferous capacity does not necessarily constitute a pest problem, and
(3) an automatic consideration of all possible pest control options before any action is taken.

They added that IPM systems consider the whole ecosystem when making pest management decisions and not just the pest organism. Each managed system is unique, with a different biotic composition and subject to varying abiotic stresses (Flint and van den Bosch, *ibid.*).

Flint and van den Bosch (*ibid.*) listed 10 major points as a guide to setting up an IPM program. These are:

(a) understanding the biology of the crop, especially in the context of how it is influenced by

the surrounding ecosystem;

(b) identification of the key pests; knowledge of their biology; recognition of the damage they inflict; and initiation of studies on their economic status;

(c) consider and identify, as quickly as possible, the key environmental factors that impinge upon pest and potential pest species in the ecosystem;

(d) consider concepts, methods and materials that individually and in combination will help to suppress permanently or restrain pest and potential pest species;

(e) structure the program so that it will have the flexibility required to adjust to change;

(f) anticipate unforeseen developments and be constantly aware of the complexity of the ecosystem and the changes that can occur within it;

(g) seek the weak links in the life cycle of the key pest species and direct deliberate control practices as narrowly as possible at these weak links;

(h) whenever possible, consider and develop methods that preserve, complement and augment the biotic and physical mortality factors that characterise the ecosystem;

(i) whenever feasible, attempt to diversify the ecosystem; and

(j) assume and even insist that technical surveillance for programs be available, e.g. monitoring

The development of an IPM program for *P. xylostella* in Barbados must take Insecticide Resistance Management (IRM) into account. According to Croft (1990), the primary goals of such a subcomponent of IPM are:

(a) avoiding resistance development in pest populations,

(b) slowing the rate of resistance development,

(c) causing resistant populations to "revert" to more susceptible levels and, thereafter,

(d) keeping resistance below some threshold.

Selection of arthropod natural enemies in the laboratory or the field by artificial means to develop resistant strains is another aspect of IRM (Croft, *ibid.*). Phillips *et al.* (1989) noted that, by adhering to the principles of IRM and using other IPM components such as biological control and cultural control, IPM has the potential of conserving the susceptibility of pests to insecticides. Croft (1990), citing a 1986 report by the United States National Academy of Sciences, listed various operational tactics for pests under an IRM program. They include varying dose or frequency of pesticide application; applying treatments only when economic levels of pests are present; using less persistent pesticides; treating only certain life stages of pests; using pesticide mixtures; using alterations, rotations, or sequences (of pesticides); using improved pesticide formulations; using synergists; exploiting unstable resistance; and identifying new toxicants with alternate sites of activity. It must be stressed, however, that IRM and even IPM programmes developed in one country or even one ecological zone cannot be readily transferred to another to obtain similar results, as many factors including weather, topography, pest biology, natural enemies, pesticide usage and socioeconomic constraints may be different. Thus, the design of an IRM implementation system is usually specific to a particular species and an ecological/management environment.

Forrester (1990) stated that once laboratory evidence confirms resistance to be the problem, then there are a series of questions that need to be answered before a resistance-countering strategy is designed. These are:

(a) What are the resistance mechanisms and cross-resistance patterns? A knowledge of these will enable the planning of sequential use patterns for the available chemical groups. It is also important to test for any possible regional differences in resistance mechanisms and cross-resistance patterns.

(b) What is the resistance status of alternate compounds? The design of a strategy must consider the resistance status of all compounds used, present and past.

(c) Are there any concurrent pests and are they resistant? Resistance management can become quite complicated in crops with multiple pests, like cabbage in Barbados. Some pests may be resistant, others not, and the resistance patterns of multiple pests may overlap. Sometimes overriding IPM considerations preclude the use of certain insecticides at specific times to preserve natural enemies and/or to prevent resurgence of other pests. Quite often, other key pests may dictate insecticide usage patterns and any strategy must be designed for the whole pest complex.

(d) What is the ecology of the key resistant pest? Information on the biology and ecology of a pest is essential in designing a resistance management strategy. It is necessary to have information on the pest's host plants, its seasonal abundance, number of generations per year and to what extent does the population mix. The latter is dependent on the pest's dispersal capacity. Once this information has been gathered, it should be possible to devise a preliminary working strategy that can be later refined by further research (Forrester, *ibid.*). Phillips *et al.* (1989) noted, however, that before the full benefits from IRM, or more importantly those from IPM, can be realized, sampling technology needs to be improved as the entire system revolves around a knowledge of the population densities of the pest and the natural enemies that exert a regulatory effect.

IPM OF *P. XYLOSTELLA*

Several attempts to develop an IPM program for *P. xylostella* have been made in several countries (Lim, 1990). Lim (*ibid.*) listed eight important common features of these IPM programs:

(a) Only a few of the potential elements have so far been practically incorporated.

(b) The most common components used are biological control agents (particularly parasitoids), action thresholds and monitoring, and judicious use of chemical insecticides when the economic threshold of the pest is exceeded. In a few cases additional elements such as crop rotation, proper time of planting, light trapping and use of a physical barrier have been incorporated.

(c) In general, none of the IPM programs are inferior to the existing prophylactic control measures presently practiced by farmers. Although crop yields may not always improve substantially, they generally are not reduced.

(d) In cases where the thresholds are exceeded and insecticidal applications are necessary, both the frequency and amount of insecticides used are substantially reduced.

(e) For most of the IPM programs, *Bacillus thuringiensis* based products have been incorporated, serving as a replacement to many broad-spectrum insecticides and providing the needed selectivity when quick action by chemical intervention is necessary.

(f) There is usually a substantial increase in terms of profit, mainly due to savings from the enormous reductions in chemical inputs.

(g) Most of the IPM programs are presently still at the experimental stage. Although there has been field adoption, this is only on a limited scale.

(h) The IPM programs are still largely executed and confined within the domain of researchers. There is presently inadequate involvement of both extension personnel and farmers.

Lim (*ibid.*) added that most research programs on *P. xylostella* management have been centered only on the biological aspects, but IPM technology adoption extends well beyond this and includes the many social and marketing factors that can influence pest control decisions.

With reference to (b) and (d) on Lim's (1990) list, Binns and Nyrop (1992) stated that decision making is a key aspect of current IPM programs and relies on protocols for deciding on the need for some management action based on the assessment of the state of a pest population and ideally its

natural enemies. These protocols, which they call control decision rules, consist of at least two components and may include a third. These are:

(a) a procedure for assessing the density of the pest population,
(b) an economic threshold level for the pest, and
(c) a phenological forecast, which is often necessary to determine the appropriate time to assess population densities.

According to Binns and Nyrop (*ibid.*), sampling is important, as assessment of pest density usually requires obtaining actual counts of the pests. They added that decision making in IPM is important for two reasons. First, decision-making protocols can be used to reduce pesticide use, particularly in crop production systems where biological control is prominent. Secondly, should biological and cultural practices fail, pest control can still be accomplished through the effective use of pesticides, and decision-making protocols must be available to determine when to intervene.

Holl *et al.* (1990) stressed that there is no one practice or combination of practices that works to control pests in all situations: each IPM system must be tailored to the specific agro-ecosystem involved. Factors to be considered when deciding which pest control techniques are most feasible for a particular agro-ecosystem include climate, crop(s), pests, soils, hydrological cycles and local natural ecosystems as well as farmers' perceptions of pest problems.

The problem of insecticide resistance in *P. xylostella* in Barbados and its effect on cabbage production is quite complex and there are many interrelating factors involved (reviewed by Gibbs, 1993). Denholm and Rowland (1992) stated that in some populations of *P. xylostella*, resistance to most available insecticides has evolved, and poses a formidable challenge in view of present difficulties in discovering and, in particular developing new chemicals with novel modes of action. They added that *P. xylostella* resistance in some countries is so intractable, extending now to the benzophenyl ureas (insect growth regulators) and even *B. thuringiensis* based products, that only cohesive IPM approaches incorporating more emphasis on non-chemical methods offer a realistic prospect of long-term control.

In tropical countries, insects like *P. xylostella* usually have rapid reproductive rates, short generation times, and generally there are overlapping generations at any given time (Jones, 1985; Sagenmueller and Rose, 1986). In Barbados, the problem with *P. xylostella* and its resistance to insecticides is aggravated by the year round cultivation of cabbage and other brassicaceous crops. In addition, the overuse of insecticides in tropical regions like the Caribbean (Gooding, 1980; Pollard, 1980) only enhances the conditions necessary for the selection of resistant strains. Pesticide misuse can also cause the destruction of non-target organisms such as the beneficial parasitoids and predators, the contamination of precious water reserves, and unnecessarily high residue levels in crop produce.

Jones (1985) stated that chemical control of *P. xylostella* remained the overwhelming practical choice of the Barbadian cabbage farmer. He added that a shift in control strategy would most likely follow an integrated approach. In such an approach, emphasis should be placed on the diversification of selection pressures on *P. xylostella* to reduce the rate at which resistance is selected. If an IPM programme for *P. xylostella* is to be devised, the development of insecticide resistance should be controlled, or delayed, when possible. Broadley (1985) suggested that this might be achieved by doing the following:

(a) Avoid the use of insecticides with high residual times.
(b) Apply insecticides at the most vulnerable stage of the insect's life cycle. Since first instar *P. xylostella* larvae mine cabbage leaves, application of contact insecticides at this stage is not very effective.
(c) Use insecticides at the recommended rates only. Sub-lethal doses and rates higher than the recommended ones, not only select for resistance, but waste money.
(d) Control drift of insecticides when applying them to the crop. This is important when

insecticides are used in mixed cropping areas, as is the situation on most small farmer holdings in Barbados.

Hama (1990) recommended a rotational application of various kinds of insecticides in order to delay or suppress the rapid development of insecticide resistance in *P. xylostella* in Japan. They should be different in terms of their modes of action or resistance mechanisms. Hama (*ibid.*) further suggested that an IPM program needs to be developed to reduce the number of insecticidal applications and to incorporate rotational applications with other techniques such as avoidance of continuous growing of brassicas, introduction of plant races resistant to *P. xylostella* and the use of sex pheromones, pathogens, parasites and predators

In Barbados, more emphasis should be placed on the selection of insecticides that have least affect on the survival of natural enemies like *Cotesia plutellae* and *Oomyzus sokolowskii*. Although there have been some additional reports on the development of resistance in *P. xylostella* to *B. thuringiensis* based products (J. Waage, CABI-IBC, Pers. comm.), these insecticides should, for some time in the future, continue to play a significant role in the control of *P. xylostella* in Barbados.

There is also a need for the introduction of additional exotic parasitoids to control *P. xylostella*, and a prime candidate could be the egg parasitoid, *Trichogrammatoidea bactrae* Nagaraja. A successful IPM technology package developed by the Asian Vegetable Research and Development Centre to control *P. xylostella* utilises this parasitoid in combination with *C. plutellae*, *Diadegma semiclausen* and *B. thuringiensis* subsp. *kurstaki* (PCCARD, 1991). *T. bactrae* might also play a vital role in Barbados, particularly in an IPM program for *P. xylostella*. The effects of the currently used insecticides on *T. bactrae* would also have to be investigated.

PROVISIONAL IPM PROGRAM FOR *P. XYLOSTELLA* IN BARBADOS

Based on the survey data (Gibbs, 1993), other factors affecting farmers decisions (weather, market price, etc.) and the results of insecticide bioassays on *C. plutellae* (Gibbs, *Ibid.*), an IPM program for *P. xylostella* on cabbage in Barbados should be structured along the following lines. Firstly, farmers should be encouraged to:

(a) Grow dark leaf (and if possible also glossy leaf) cabbage varieties. These tend to be more resistant to *P. xylostella* (Gibbs, *Ibid.*).

(b) Where irrigation is available, use overhead sprinkler systems and irrigate from dusk onwards. This practice interrupts flying-mating activities in *P. xylostella* moths and would lead to decreased oviposition.

(c) Plant cabbage during the wetter months of the year. *P. xylostella* larvae can be washed away or drowned by rain.

(d) Restrict fertilizer use to recommended rates. Overuse not only leads to increased production costs but adds to the cabbage plants' "attractiveness" to *P. xylostella* and other pests.

(e) Replace use of conventional type insecticides, particularly those to which *P. xylostella* has shown resistance, by *Bacillus thuringiensis* (Bt) based products and, preferably, insect growth regulators (benzophenyl ureas and similar compounds). These products have different modes of action to those of the conventional insecticide types (organophosphates, pyrethroids, carbamates) and have been shown to be relatively non-toxic to beneficial organisms like *C. plutellae*. Bt has also been shown to significantly reduce the feeding rate of *P. xylostella* (Hoy and Hall, 1993), an added advantage.

(f) Farmers should always use the manufacturers' recommended rates and frequencies of insecticide application.

(g) Conserve populations of natural enemies like *C. plutellae* and *O. sokolowskii* by employing component (e) above and by providing some refugia including nectar producing plants. Extensive use of herbicides to destroy all surrounding wild vegetation should be avoided

as this would destroy possible refugia sites for natural enemies and might also kill some of their populations by direct contact with herbicide.

In addition, research should be conducted to provide information to farmers on which chemicals have the least mortality impact on natural enemy populations in the field. Seminars/field days should be organized to show to farmers the correct usage of insecticides, i.e. what are the various types of insecticides available in Barbados, how they work and how to correctly apply them, stressing that they should be used only at their recommended rates and frequencies. A farmer training program on the safe use and proper handling of pesticides like that outlined by Sjerven (1991) for farmers in Indonesia, would be very appropriate and timely for cabbage farmers in Barbados.

ADOPTION, CONSTRAINTS AND FUTURE RESEARCH

With respect to the use of dark leaf (glossy) cabbage varieties, this aspect of the IPM program may be best achieved by convincing the seed retailers in Barbados of the resistance qualities exhibited by these varieties. Resist Crown, a dark leaf hybrid, is already available in Barbados and has shown lower levels of crop loss due to *P. xylostella*.

One constraint to the use of overhead sprinkler irrigation to suppress *P. xylostella* activity is that most of the cabbage farmers in Barbados who use supplemental irrigation, have drip irrigation systems. This latter type of irrigation is encouraged as it costs less, both in terms of equipment and water usage. It uses much less water than the overhead sprinkler system and puts the water where it is most needed and utilized. However, there are some farmers who still use the overhead sprinkler system and it is to these farmers that efforts would have to be made to convince them of its effectiveness in suppressing *P. xylostella* populations. The survey revealed that most of the cabbage farmers in Barbados grow cabbage as a rain-fed crop, and thus will be utilizing the possible effects of the rain in washing away and drowning some *P. xylostella* larvae on their cabbage crops.

To some extent, parts of the proposed IPM program above have already taken place. The insect growth regulator Jupiter(R) 120EC, 12% chlorfluazuron (CIBA-GEIGY, Switzerland) became commercially available to farmers in Barbados in 1991, after one author (I.H. Gibbs) had discussed the *P. xylostella* problem of conventional insecticide resistance with one of the island's agrochemical retailing companies. Cabbage farmers were also advised not to use Jupiter(R) exclusively, but to rotate its use with Dipel(R) (*B. thuringiensis* subsp. *kurstaki*). Since then, many farmers have adopted this advice, resulting in considerable reductions in *P. xylostella* populations on their cabbage crops and substantial increases in the availability of the produce in the markets (Fig. 2). However, it is inevitable that *P. xylostella* will, at some time in the future, develop resistance to Jupiter(R). Based on this inevitability, a series of insecticide trials against *P. xylostella* on cabbage have been recently initiated (Chinnery *et al.*, 1993), in which other insecticide growth regulators such as teflubenzuron, flufenoxuron and azadirachtin are being investigated as possible replacements for Jupiter(R). Ultraviolet light protectants are also being evaluated to prolong the effectiveness of *B. thuringiensis* products in the field.

P. xylostella resistance to products based on the ä-endotoxin of *B. thuringiensis* (Bt) has already developed in many countries (e.g. Kirsch and Schmutterer, 1988; Tabashnik *et al.*, 1990) and is inevitable in Barbados. The high hopes for genetically engineered *Brassica* plants, in which the Bt gene is expressed, prominent in temperate countries (e.g. Bai *et al.*, 1994) would most certainly not be fulfilled for cabbage in the tropics.

Hill (1983) reported that 10-15 generations are required in most insect species for resistance to manifest itself. Thus, with continuous breeding of pest species with overlapping generations, insecticide resistance can rapidly develop in the tropics. For diamondback moth, which produces as many as 30 overlapping generations per year in Barbados (Jones, 1985), it would be expected that any population exposed to these genetically engineered plants for four to six months would develop resistance. Not only making the transgenic plants useless to the farmer, but also eliminating

the analogous Bt insecticide from the IPM package.

The use of entomopathogenic fungi against *P. xylostella* is another area for future research. Field experiments in Malaysia have shown the efficacy of two species, *Beauveria bassiana* and *Paecilomyces fumosoroseus* (Ibrahim and Low, 1993), with the entomopathogens leading to significantly more marketable heads than plots alternately sprayed with cypermethrin (Cymbush(R)) and phenthoate (Elsan(R)). Plants sprayed with *B. bassiana* and permethrin (Ambush(R)) were equally likely to reach a marketable size as plants treated with this fungus alone.

At this time, dead and dying insects found in the field, that appear to be infected with pathogens, are brought to the plant pathology laboratory at the University of the West Indies. Fungi, and bacteria, cultured from the pest are identified and cultures of potential entomopathogens are placed in storage for future evaluation.

Spiders are voracious feeders and, depending upon the species, can consume 11 to 221 larvae of diamondback moth per day (Mansingh, 1994). Research is needed to determine the species present and ways to augment the populations of those feeding on *P. xylostella*. Since spiders are highly susceptible to insecticides, the current program using less, and more specific, insecticides may already be benefitting from increased spider predation.

A simple, practical, "farmer-friendly" sampling method, based on a realistic economic threshold limit for *P. xylostella*, needs to be developed. This would, hopefully, persuade farmers to apply insecticides only when required by the results of the above-mentioned sampling method, and not as many do now on a calendar basis. Smith (1970) stated that fixed treatment schedules, such as treatments by the calendar, are almost certain to result in many unnecessary pesticide applications thus intensifying the problem of resistance. He added that such rigid treatment schedules not only give natural enemies no refuge or chance for recovery, but have also caused severe resurgence of target pests and the rise of secondary pests, both conditions requiring still additional treatments and intensification of resistance selection.

Although, a few of the components of the suggested IPM program for *P. xylostella* in Barbados are already being used by cabbage farmers, convincing them to adopt the others will be the next challenge, as cabbage is a high value cash crop and Barbadian consumers now require produce that is mostly, if not entirely, blemish free.

The IPM program for *P. xylostella* on cabbage in Barbados was also prepared, considering the fact that this is not the only pest of cabbage in the island (Chinnery *et al.*, 1993). The judicious use of newer insecticides with modes of action different from the conventional insecticides previously used on the crop was strongly suggested together with their rotation with *B. thuringiensis* based products. This strategy should delay the development of resistance in *P. xylostella* to these insecticides besides conserving field populations of important parasitoids like *C. plutellae* and *O. sokolowskii*.

Furthermore, the adoption of this program should enable farmers to produce quality cabbages and reduce the levels of toxic insecticide residues and the risk of human and environmental pesticide contamination.

Since effective IPM requires continuous field research and farmer education, it has caused a change in the role of extension entomology (Allen and Rajotte, 1990). In most Caribbean countries, there are very few professional entomologists, and other pest management professionals. The development of IPM programs for all our crop/pest combinations will require a serious reallocation of financial resources and expansion of manpower. This will only occur if the crop scientists of the region effectively educate the public of the general benefits of IPM.

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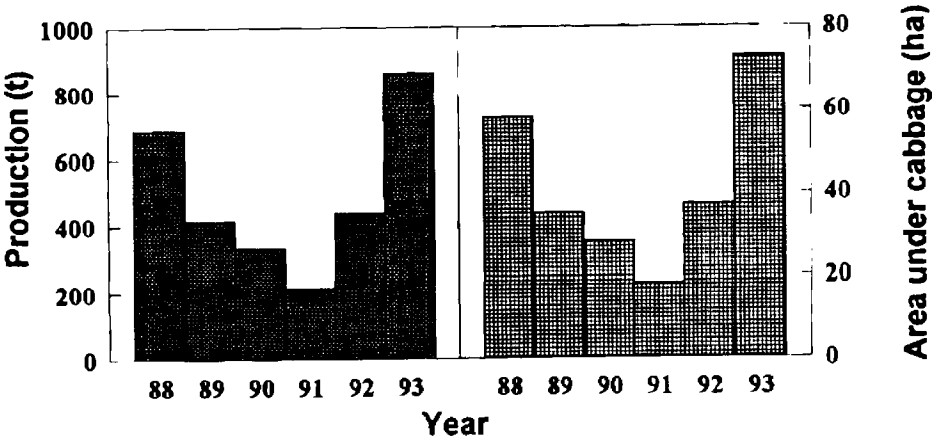

Fig. 1. Cabbage production in Barbados 1980-1991 (After Chinnery *et al.*, 1993).

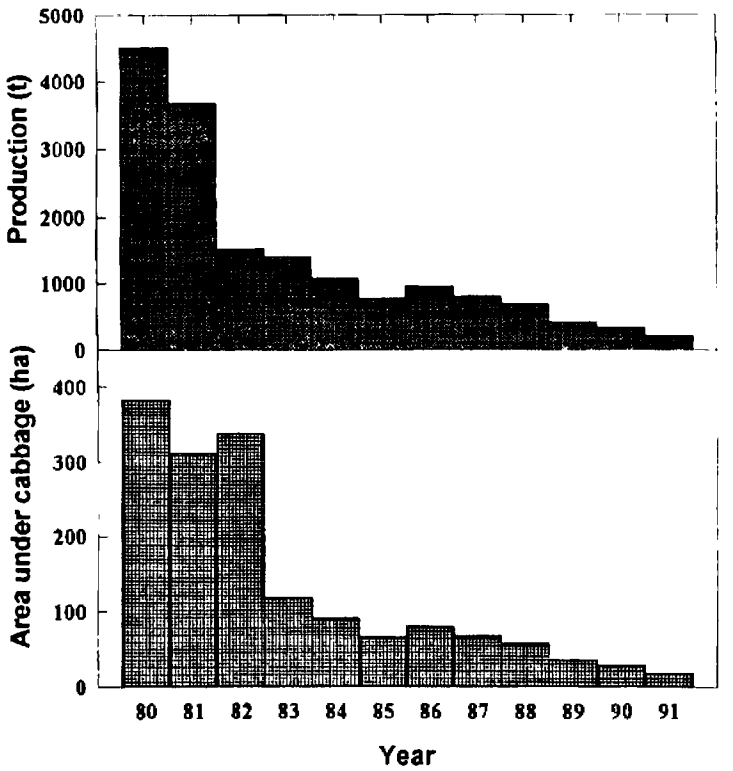

Fig. 2. Recent changes in cabbage production in Barbados.

WEED MANAGEMENT IN A PIGEONPEA-TOMATO CROPPING SYSTEM

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ABSTRACT

Pigeon pea-tomato cropping sequence was initiated in July 14, 1993 at Juana Diaz, Puerto Rico to evaluate weed suppression from pigeon pea residues and herbicides. Herbicides such as metribuzin (0.56 kg ai/ha), prometryn (2.24 kg ai/ha), oxyfluorfen (0.28 kg ai/ha), and imazethapyr (0.07 kg ai/ha) applied pre-emergence to pigeonpea decreased weed density up to 100 % for the first two weeks. Weed density increased after four weeks and no differences were detected among herbicides. Pigeonpea yield ranged from 2026 kg/ha (green pods) with imazethapyr to 2980 kg/ha with handweedings. Weed density was evaluated in a tomato transplanted in the same plots March 4, 1994. Weed density was not significantly different among previous herbicide treatments applied to pigeon pea. Average reduction in weed density was 57% in plots where pigeonpea was grown and incorporated.

INTRODUCTION

In tropical areas weed control problems are particularly acute due to continuous cropping, with overlapping growing seasons, and the absence of cold periods that interrupt life cycles of weeds. In Puerto Rico, weed management programs for tomatoes include handweeding, mechanical cultivation, and chemicals in combination with plastic mulching (Liu, 1990). None of these methods alone provide full-season control of existing weeds. Weed control cost in tomatoes could be from 44 to 77% of total expenses. New management strategies are needed to enhance weed control and reduce production cost in tomatoes.

Crop rotation, for the utilization of allelopathic plant residues or herbicide sequences, is a potential strategy which could be integrated in tomato management system to supplement current practices of weed control. The results of several studies indicate the potential benefits which pigeonpea rotation may have in crop production systems (Bosque-Fernández, 1986; Hepperly and Diaz, 1983; Talleyrand et al., 1977). Pigeonpea has demonstrated allelopatic activity against weeds (Hepperly et al. 1992). The combination of the allelopathic effects of pigeon pea and the residual activity of herbicides could be used to enhance weed control in tomato.

The objective of this study was to evaluate weed suppression from pigeonpea residue and herbicides in a pigeonpea-tomato cropping system.

MATERIALS AND METHODS

A field experiment was established with Kaki pigeon pea plantings July 14, 1993 at Juana Diaz, Puerto Rico. The soil belongs to the San Anton series (fine-loamy, mixed isohyperthermic). A two-way split plot design was followed with four replications. Main plots were four pre-emergence herbicides applied to pigeon pea one day after planting. Plot consisted of twelve rows 0.91 m apart and 6.1 m long. Subplots consisted of two equal areas of six rows; one area in which pigeonpea was planted (+PP) and another that was not planted to pigeonpea (-PP). Herbicides treatments included imazethapyr (0.07 kg ai/ha), metribuzin (0.56 kg ai/ha), prometryn (2.24 kg ai/ha), and oxyfluorfen (0.28 kg ai/ha), and the untreated check. Untreated plots were handweeded from three to nine weeks after planting (WAP). Green pigeonpea was harvested in January 27, 1994. The remaining

plant material was mowed and disked for soil incorporation five days later.

Seedbeds were well prepared and tomato seedlings were transplanted in March 4, 1994 in the same plots where the preemergence herbicides were applied to pigeon pea. Six rows of tomato (cv. Duke) were transplanted 1.82 m apart in the main plots. Three rows were planted for subplots. Metribuzin at 0.35 kg ai /ha was applied over the top of tomato one week after transplanting (WAT). Weed density by species was recorded three and six WAT. Grass weeds were controlled with fluazifop-P (0.28 kg/ha) postemergence at third week. Weeds emerging between rows were controlled mechanically after third week. Data on tomato fruit number were recorded from May 24 to June 1, 1994. Fruit number was recorded by sampling immature and mature tomatoes from three plants. Fruit yield and quality was severely affected by insect damage at the end of May, and for these reason data on fruit number will be presented only.

The main effect of weed control treatments as well as the possible interaction between pigeonpea treatments and herbicides were analyzed using the statistical analysis system and LSD test at 0.05 probability level.

RESULTS AND DISCUSSION

Predominant weed species in the experimental area were junglerice (Echinochloa colona L.) and small spider flower (Cleome gynandra L.). Metribuzin, prometryn, oxyfluorfen, and imazethapyr significantly reduced weed density in pigeonpea for the first two weeks, when compared to the untreated check (Table 1). There were no differences in weed density among herbicide treatments at 4 WAP. Reduction in weed density in the untreated plots was due to handweeding performed after third week. Green pod yield ranged from 2026 kg/ha with imazethapyr to 2980 kg/ha with handweeding, however, differences were not significant at the 0.05 probability level. Thus, herbicide efficacy was as good as the handweedings in pigeonpea.

Table 1. Weed density and green-pod yield from pigeonpea treated with pre-emergence herbicides[a].

Treatment	Rate	Weed number/0.5 m^2		Pod yield
	kg ai/ha	2 WAP[b]	4 WAP	(kg/ha)
Imazethapyr	0.07	6 b	67 a	2026 a
Metribuzin	0.56	11 b	36 a	2397 a
Prometryn	2.12	1 b	11 a	2968 a
Oxyfluorfen	0.28	0 b	34 a	2432 a
Untreated[c]	-	71 a	11 a	2980 a

[a]Means followed by the same letter are not significantly different according to Fisher's protected LSD test at $P \leq 0.05$.
[b]Abbreviations: WAP = Weeks after planting.
[c]Handweeded from 3 to 9 WAP.

Weed density was not different among the five herbicide-sequences, either with pigeonpea (+PP) or without (-PP) pigeonpea incorporation (Table 2). However, pigeonpea decreased weed density compared to plots without pigeonpea. Incorporation of pigeonpea reduced average weed density by 57%. Tomato yield was affected by insects, especially the super lopper (Pseudoplusia includens)

which caused severe fruit damage. For this reason fruit number was recorded as the yield indicator. No significant differences were detected for tomato fruit number recovered with herbicide treatments, irrespective of pigeonpea incorporation.

Table 2. Herbicide-sequences effect on weed number and tomato fruit number[a].

Treatment[b]	Weed number/0.5 m^2		Fruit number/ha	
	-PP[d]	+PP[d]	-PP	+PP
Imazethapyr-MET-F[c]	106 a	28 a (73[e])	53490 a	47522 a
Metribuzin-MET-F	75 a	43 a (43)	50000 a	35022 a
Prometryn-MET-F	67 a	42 a (37)	34910 a	53153 a
Oxyfluorfen-MET-F	86 a	53 a (38)	35022 a	50900 a
Untreated-MET-F	101 a	20 a (80)	30068 a	30743 a
Mean	87 A	37 B (57%)	40698 A	43468 A

[a]Means followed by the same letter are not significantly different according to Fisher's protected LSD test at $P \leq 0.05$.
[b]Same treatments applied to pigeon pea. See Table 1 for herbicide rates.
[c]Metribuzin (MET) at 0.35 kg ai/ha was applied over the top of tomato one week after transplanting followed by fluazifop-P (F) at 0.28 kg ai/ha the third week.
[d]Abbreviations: +PP = with pigeon pea, -PP = without pigeon pea.
[e]Numbers in parenthesis means percent weed reduction by pigeon pea.

CONCLUSIONS

A pigeonpea crop with or without herbicides decreased weed density in the following tomato crop. Weed reduction in tomato can be attributed to allelopathic interference from pigeonpea residues. Pigeonpea enhanced weed control of the standard metribuzin treatment applied early post-emergence to tomato. A pigeonpea-tomato cropping system may be possible in terms of weed suppression, however, further studies need to be conducted to evaluate pigeonpea effect on tomato yield.

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INTEGRATED CROP MANAGEMENT STUDIES IN ONIONS ON ST.KITTS AND NEVIS

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ABSTRACT

Onion (*Allium cepa* L.) production is susceptible to weed interference due to delayed germination and initial slow crop growth. A series of trials were conducted during 1991/94 to determine the critical period of weed competition, varietal selection, herbicide evaluation, and the effects of rolling and depth of seeding. The study demonstrated a critical period of weed competition of 0 to 50 days after emergence, ie. the crop must be kept essentially weed-free, and that Assure at seeding depth of 3.75 cm and Dacthal and Prowl (1.25 cm) are the most promising herbicides for var. Grandstand. However, in varietal trials var. Special 38 and Grandnoble produced significantly higher yields than Grandstand. Yields of Grandstand were improved significantly in 2 of 3 locations when seed-beds were rolled regardless of seeding depths. NPK(12:12:20) @538kg.ha^{-1} at planting plus sulphate of ammonia(384 kg.ha^{-1}) and muriate of potash (234kg.ha^{-1}) split application at planting and 6 WAE is recommended. The potential of onions grown under adequate weed-free conditions for periods of up to 60 DAS varied between 39.5 to 55 t.ha^{-1}.

INTRODUCTION

Onion (*Allium cepa)* accounts for 23% of the total vegetable imported into St. Kitts - Nevis. The country has the potential to produce 50% [125,000 kg] of the total domestic requirements. Production has increased both in terms of acreage established and productivity (Fig.1). Cultivations are characterized by small to medium sized plots under rainfed conditions and manual field operations and limited to the periods October to April. The major constraints to production are the high cost of manual labor, lack of irrigation, inadequate post harvest facilities, and weed control (Charles,1976., Ameen and Azenkot, 1991., Weekes,1993).

Onions exhibit greater susceptibility to weed competition than most other vegetable crops, and in the absence of any control practice total crop loss is not uncommon (Brathwaite and Bridgemohan, 1988). Onion's slow germination and early growth, and absence of dense foliage predisposes it to severe initial competition (Hewson and Roberts, 1973). Early weed control is essential for any economical yield. Wicks *et al.* (1973) found that weeds present for only 2 weeks following crop emergence can thwart crop growth. Weed competition studies have indicated that the crop should be weed-free for the first third of the growing season, or that no reduction in yield occurred if weeds were removed 4 to 6 weeks after crop emergence (Chubb, 1962., Hewson and Roberts, 1971). Carr (1969) reported that Tok E 25 was a successfull pre-emergence herbicide in onion, but this has now been banned. This is replaced by various chemicals whose efficacy are variable depending on the weed population, existing weed seed bank and previous cropping patterns (Chandler, Pers.Comm., 1994).

Weeds compete with onions for growth resources resulting in a reduction in crop yield through reduced leaf blade and leaf-number, bulb number and size, depressed photosynthetic capacity (Shadbolt and Holm, 1956). Roberts (1973) reported that no new leaves are formed after bulbing and the number and size of leaves present at that time determines eventual bulb size. Weeds removed approximately one-half the available nitrogen and one third the potassium during initial competition, but competition for moisture predominated later in the growing

season (Zimdhal, 1980).

To improve crop productivity and quality an integrated crop management approach to reduce the limiting growth factors are essential. This study attempted to address some of these problems through specific objectives :

i. to determine the critical period of weed competition,
ii. to evaluate the response of varying seeding depths, effects of seed-bed rolling,and herbicides on the growth, development and yield of onions,
iii. varietal selection in response to productivity, quality, adaptability to agro-ecological conditions, and tolerance to pest and disease, and
iv. fertilizer response.

MATERIALS AND METHODS

Most of the trials were conducted at the CARDI field station in St. Kitts on soils where no herbicides were used on previous cultivations. The soil is a sandy loam [Protosols] described as coarse soils over loose volcanic ash [Lang and Carrol, 1966]. The crop was seeded at the rate 5.5 $kg.ha^{-1}$ on raised beds, using a precision seed™at a depth of 1.5 to 2 cm. Plot size was $4.8m^2$ and experimental plot 1 x 3m ($3m^2$) with 5 rows. All agronomic practices were conducted as recommended by Leach (1991), Ross *et al*,(1991) and Azenkot (1993).

The observations recorded included meterological data, presence of persistent weeds prior to land preparation, days to 50% seedling emergence, herbicide injury, crop growth parameters viz. plant height and number of leaves, time to bulbing and senescense and yield and yield components. At harvest the weed density/cover were visually estimated using a rating of 0 to 5, where 5 = no weeds or excellent control, and 0 = dense stand or no control in a $0.25m^2$ quadrat.

STUDY I: Critical period of weed competition in onions.

The treatments were weed-free and weed-infested at 0 to 60 days after sowing (DAS) in increments of 10 days. The plots were essentially weed-free (WF) by regular manual weeding for the above periods after which the weeds were allowed to grow until harvest, or kept weed infested (WI) for the above period, after which they were kept weed-free until 70 DAS. The controls were weed-free and "weedy-check." The weed-free treatment involves removal of all the weeds at 10 day intervals until 60 DAS, while in the "weedy check" the weeds were left unattended. The experimental design was randomized complete block with 7 treatments and 3 replicates. All data were analyzed using the statistical package ANOVA, and regression analysis were conducted for the critical period of competition and the best fit model reported.

STUDY 2: Evaluation of depth of seeding, rolling and chemical weed control in onions.

The trial was conducted during the same period as Study 1. Plots size and all cultural practices were similar to that previously reported. The treatments were 3 seeding depths (1.25, 2.50, and 3.75 cm), rolling and non rolling, and 6 herbicides (Table 1). The controls were weed-free and "weedy-check." The onion seeds var. Grandstand was planted using a precision seeder with adjustable planting depths, while rolling was done using a 1m wide concrete roller (40kg). All the herbicides were applied with a knap-sack sprayer using T-jet nozzles and water as the carrier. No adjuvants were used. The treatments were laid out in a randomized block design with 2 replicates, and the data analysed as a factorial arrangement using statistical package GLIM.

Table 1. Name and rates of herbicides used in trial.

Herbicide	Common name	Rate ai.kg.ha^{-1}	Chemical name
Goal	oxyflourfen	0.06	2-chloro-1-(3-ethoxy-4-nitrophenoxy) -4-triflouromethylbenezene
Fusilade	Fluazifop-butyl	0.5	Butyl2-[4(5triflouromethyl-2-pyridyloxy)phenoxy] propionate
Assure	Quizalofop-ethyl	0.05	Ethyl-2-[4chloroquinoxalin-2-yloxyphenoxy]propionare
Dacthal	chlorothal	9	Dimethyl tetrachloroterephthalate,
Prowl	Pendimethalin	4.5	N-(1-Ethylpropyl)3,4-imethyl-2,6dinitrobenezenamine
Ramrod	Propacholor	2.75	2-Chloro-N- isopropylacetanilide.

STUDY 3: The effects of rolling and seeding depths on the establishment and yield of onions.

This trial was conducted at three locations using a split-plot factorial arrangement with rolling as the main plot, and depth of seeding as subplots. The main plot treatments were: no rolling (NP), rolling before planting (RBP), rolling after planting (RAP), and rolling before and after planting (RBAP). The roller used was the same as in study 2. The seeding depths were 1.25, 1.75, 2.5, 3.0, and 3.75 cm, and the variety was Grandnoble. All other management practices were similar to Study 1 and 2.

STUDY 4: Varietal selection in onions.

Trials were established in October, 1992 evaluating the adaptability and yield performance of four vars. Grandstand, Special 38, Texas Grano 502, and Grandnoble on two farms in Nevis and four farms in St.Kitts. All the trials used similar layout and experimental designs (RCBD),and similar crop management practices.

STUDY 5: Fertilizer response trials.

This trial was conducted on two sites (Taylors Range and New River) during 1993. The field trial management was similar to those reported above. The treatment evaluated were NPK (12:12:20), sulphate of ammonia (SOA), and muriate of potash (MOP) at varying rates and time of application (Table 2). The control was no fertilizer. The experiment was a CRD with 5 treatments and 6 replicates.

Table 2. The various fertilizer treatments according to rates and time of application evaluated in two locations.

Treatments	@planting	followed-by
1	NPK	SOA + MOP(78kg.ha^{-1}) @ 4,8 and 10 WAE
2	NPK + SOA	SOA + MOP(117kg.ha^{-1}) + MOP(117kg.ha^{-1})@6WAG
3	NPK @ 4 WAE	SOA + MOP(78kg.ha^{-1}) @ 8 and 10 WAE
4	NPK	SOA + MOP(78kg.ha^{-1}) @ 4 and WAE

where rates of NPK = 538 Kg.ha^{-1}
SOA = 348
WAE = weeks after emergence

RESULTS AND DISCUSSION

Rainfall recorded during the cropping period was 350 mm and supplemented by drip irrigation. There was no significant variation in the mean sunshine ($10hr.day^{-1}$) and the mean maximum temperature 29.3°C.

STUDY I: Critical period of weed competition in onions.

The crop exhibited 95% emergence at 13 DAS and was harvested at 110 DAS. The results indicated that keeping the plots WF 0 DAS or WI 50 to 60 DAS produced no harvestable yield . Increasing the periods of WF treatments increased yields exponentially, while increasing the periods of WI decreased yields exponentially (fig. 2). The crop reached a maximum yield of 24.9 to 27.3 $kg.plot^{-1}$ when grown under WF conditions from sowing to 50 and 60 DAS, respectively. Plots that were kept essentially WF 50 and 60 DAS incurred yield reduction of 8.6 and 0%, respectively, while WF 10 to 40 DAS incurred yield reductions of 97 to 17.4%, respectively .

Plots kept WI 0 to 10 DAS yielded 19.4 $kg.plot^{-1}$. Increasing the WI periods from 20 to 60 DAS resulted in yield reductions of 31.3 to 100%. This suggests that the maximum period that the crop should be kept WI is less than 10 DAS, otherwise a 30% yield reduction occurs immediately after (fig.3). If one were to accept a 10% loss due to weed infestation, then its essential to maintain the plots WF for a minimum of 50 DAS. Wicks *et al.*(1973) observed that dried-seeded onions require weed-free maintenance for more than half the life-cycle, unlike other crops which require at least a weed-free period of one third. Mtaita and Limbadia (1990) reported a critical period of 6 weeks of weed competition for transplanted onions with a weed population similar to this trial.

Zimdhal (1980) stated that the critical period of weed competition in onions reflected the time span when weeds present from beginning of the crop must be removed, or the point after which weed growth no longer affects yield. Bridgemohan and Weekes (1993, Unpubl.) observed that even though that the crop may be free of weeds during that critical period, weeds emerging after field-curing affected the crop quality. This suggests that researchers will need to to improve both yield and quality by managing weeds during the entire crop development including removal. A list of common weeds identified during the period of interference in onion trial is presented in Table 3.

Table 3: List of common weeds identified during the period of interference in onion trial.

Annual grasses	Annual broadleaf	Perennial weeds
Elusine indica	*Cleome viscosa*	*Cynodon dactylon*
Digitaria ciliaris	*Amaranthus dubius*	*Cyperus rotundus*
	Portulaca oleracea	
	Phyllanthus amarus	

STUDY 2: Evaluation of depth of seeding, rolling and chemical weed control in onions.

The crop exhibited 100% emergence at 13 DAS and was harvested at 112 DAS. Onion yield was influenced by an interaction between weed management and depth of seeding (Table 4). As sowing depth increased from 1.25 to 3.75cm, mean plot weight of onions in the plots treated with Goal, Dacthal, and Prowl decreased, remained constant for Fusilade, and increased with Assure (fig.4). At shallow depth (1.25) all the herbicides produced as good as the weed-free, with Prowl and Dacthal producing significantly higher. Assure x depth 3.75 cm, and Dacthal x depth 1.25cm have

the potential to yield in excess of 37.9t.ha^{-1}. These yields are excellent and comparable to those obtained in earlier trials on St. Kitts (CARDI Ann. Rep., St.Kitts/Nevis, 1990/91). The response of weed control and percentage competition to the varying treatment showed that only weed management had any significant effect (Table 4), and there was an interaction between depth of sowing and rolling on percentage weed control (Table 5). The effect of the various herbicides an the yield and yield components of onions are presented in Table 6.

TABLE 4: The F-ratio for the different treatments evaluated in Onion weed management studies

Source of variations	df	Bulb number	Bulb Yield	Avg bulb weight	Plot weight	% control	% grasses	% broad leaved	% sedges
Blocks	1	0.0	2.19	3.41	2.51	4.17	0.17	47	9.74**
Weed mgt.	7	13.03**	16.85***	2.78*	16.71***	15.09***	8.93***	9.85***	4.43***
Depth	2	0.61	3.12	1.15	7.97**	1.52	0.10	0.17	0.05
Rolling	1	0.13	0.16	0.51	1.64	1.77	0.28	0.01	2.84
Weed mgt x depth	14	1.14	1.23	0.55	2.42*	1.15	1.16	1.24	0.55
Weed mgt x Rolling	7	0.74	1.25	0.53	0.23	1.24	0.82	0.59	1.84
Depth x Rolling	2	0.26	0.30	0.27	0.26	4.24*	0.02	0.23	0.10

*, **, *** = significant at 95, 99, 99.9% respectively.

TABLE 5: Interaction between depth of sowing and Rolling effects on % weed control in onions

Treatment	Depth of sowing (cm)		
	1.25	2.5	3.75
Rolling	2.5*	0.85**	3.93*
No rolling	1.1	0**	0.24

Approx. S.E.M. (59df) unmarked values (16 obs) 0.30
* " (17 obs) 0.29
** " (15 obs) 0.31

TABLE 6: Effect of various herbicides on the yield and yield component of onions.

Treatments	nos of observations	Bulb number.m^{-1}	Bulb Yield (g).m^{-1}	Avg Bulb wt(g)
Goal	11	23.8 (2.8)*	794 (106)*	32.9 (4.4)**
Fusilade	12	26.3 (2.7)	984 (101)	38.1 (4.3)
Assure	12	30.9 (2.7)	1293 (101)	44.5 (4.3)
Dacthal	11	24.2 (2.7)	814 (101)	32.5 (4.3)
Prowl	11	21.8 (2.8)	897 (111)	44.5 (4.7)
Ramrod	12	8.7 (2.7)	194 (101)	26.5 (5.2)
weedfree	13	21.8 (2.6)	1028 (97)	49.4 (4.1)
weedy-check	11	0.9 (2.8)	53 (1.06)	38.6(14.7)

* Approx. S.E.M. [58 d.f]
** Approx. S.E.M. [47 d.f]

STUDY 3: The effects of rolling and seeding depths on the establishment and yield of onions.

Rolling effects were more significant in influencing mean plot weight than seeding depths in all three locations (Table 7). In Taylors Range, rolling before, and rolling before and after increased yield significantly over the the other treatments (Table 9), while rolling effects had more impact on yield in Lynches. Neither rolling or seeding depth had any effect at Philips, but yields were significantly higher than the other two locations. It is suggested that the variability in response to rolling effects can be related to soil type and its relative soil moisture which may enhance seed to soil contact and germination . This is supported by the fact that Taylors Range is on a sandy loam compared the other locations which are sands (Lang and Carrol,1966).

Table 7 . F- ratios of the mean plot weight (kg) for the effect of rolling and seeding depth at three locations : Taylors Range (A), Philips (B), and Lynches (C).

Source of variation	df	F-Ratio's		
		A	B	C
Rolling before	1	44.03	12.83	3.11
Rolling after	1	0.18	0.14	9.48
Rolling before &after	1	211.81	0.03	0.85
Depth of seeding	4	1	1.41	2.77
Rolling before x depth	4	1.38	0.73	1.95
Roling after x depth	4	1.03	0.38	2.9
Rolling before and after x depth	4	0.07	0.77	5.21

Table 8 . The effect of rolling before, and before and after on the mean plot weight on onion for three locations.

Locations	df	Rolling	Rolling before	SED
Taylors Range	6	8.06	4.09	0.42
Lynches	3	2.89	2.5	0.36
Philips	3	12.65	10.61	1.34

STUDY 4: Varietal selection in onions.

The results indicate there were significant variations in the performance of the crop between locations and varieties (Fig. 5 and 6). Yields of Special 38 and Grandnoble were significantly different from each other, but were consistently higher than Grandstand and Texas Grano 502. The variation between locations can be accounted for by the untimely application of crop management practices viz. weed control. This substantiates early evidence of the deleterous effect of delayed weed management (Kasasian, 1971; Hammerton, 1974). It is suggested the planting of Texas Grano 502 should be discouraged. Further, Special 38 has been taken off the market by ARCO seeds.The varieties Grandstand and Granoble are recommended, although Grandstand exihibts better storage characteristics (Small and Chandler, 1990.,Chandler, 1994 ,Unpubl.). The varieties H-8,H-60 and

Ben-Shemen performed reasonably well and are recommended because of their long shelf life (Azenkot,1993).

STUDY 5: Fertilizer Response trials.

Table 9. The response of onion marketable yield (kg.plot^{-1}) to varying types, rates, and timing of application of fertilizer.

Treatment	Taylors Range	New River
1	2.31	5.7
2	2.46	5.3
3	1.75	4.6
4	1.95	5.6
5	1.69	4.4
SEM (18df)	0.19	0.54
CV (%)	19.65	24.95

The results indicate that the responses to treatments 1 and 2 were similar, and improved yield significantly compared to the other treatments (Table.9). This suggests that the cost of fertilizer applications can be lowered by reducing the number applications as in treatment 2. The efficient use of nitrogen split at recommended rates into two or more application during the season was suggested by Forde and Walmsley (1977) , Curven *et al.* (1988), and Azenkot (1993). Similar responses were observed by Leach (1991), Ross *et al.*, (1991) and Chandler and Weekes (Pers. comm.,1994).

An integrated crop management approach is the key to improving onion productivity. Transfering single technologies independently without testing its interactive effect on other practices may not improve yield effectively, and may reveal variations between experimental plot yield and farmers yield even after adjustments are made. This series of trials provide some recommendations which can now be integrated further and validated for both biological and economic efficiency.

This study demonstrated -

(i). the critical period of weed competition in onion is 0 to 50 DAS, ie the crop must be kept essentially weed free throughout the period, in order to reduce yield loss to <10% due to weeds,

(ii). potential yield of onions grown under WF 60 DAS and WI 10 DAS range between 56 and 39.8t.ha^{-1}.

(iii). weed management had more effect on onion yield components than seeding depth and rolling effects,

(iv). increasing sowing depth resulted in increased yield per plot for Assure with an opposite response for Goal, Dacthal and Prowl.

(v). Assure at seeding depth of 3.75cm and dacthal and prowl at seeding depths of 1.25cm are the most promising pre-emergence herbicides in onion.

(vi). Var. Grandstand and Grandnoble are recommended in terms of yield potential only, and

(vii). NPK(538kg.ha^{-1}) plus sulphate of ammonia (192kg.ha^{-1}) and muriate of potash (117kg.ha^{-1}) @ planting, followed-by sulphate of ammonia (192kg.ha^{-1}) and muriate of potash(117kg.ha^{-1}) at 6weeks after emergence as the recommended fertilizer

for the crop.

This information is important in developing an integrated crop management strategy that allows the farmer to apply different technologies at minimum cost and obtain maximum productivity and efficiency.

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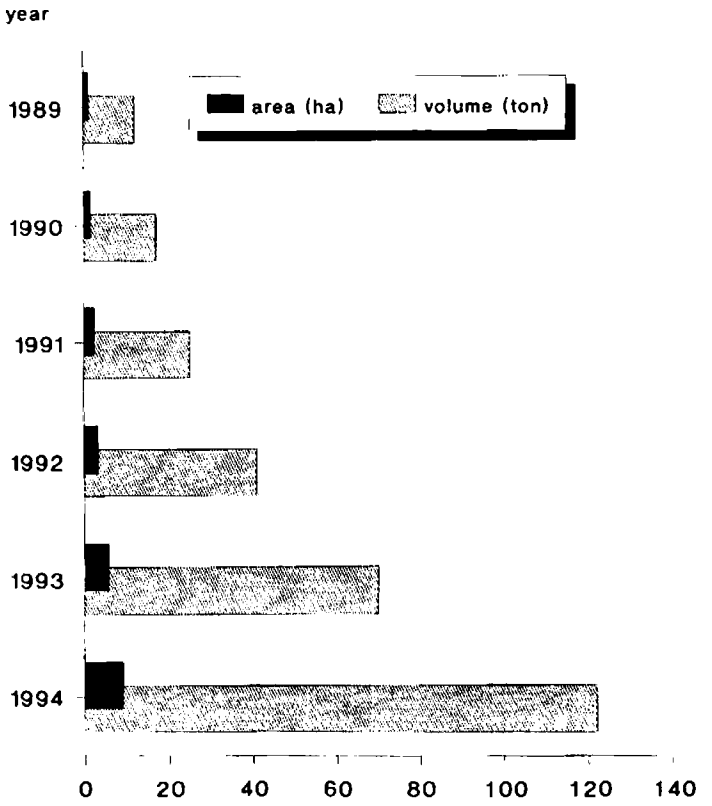

Fig. 1. Onion production (1989-1994) St. Kitts and Nevis. (Source: CARDI/MOA St. Kitts, 1994).

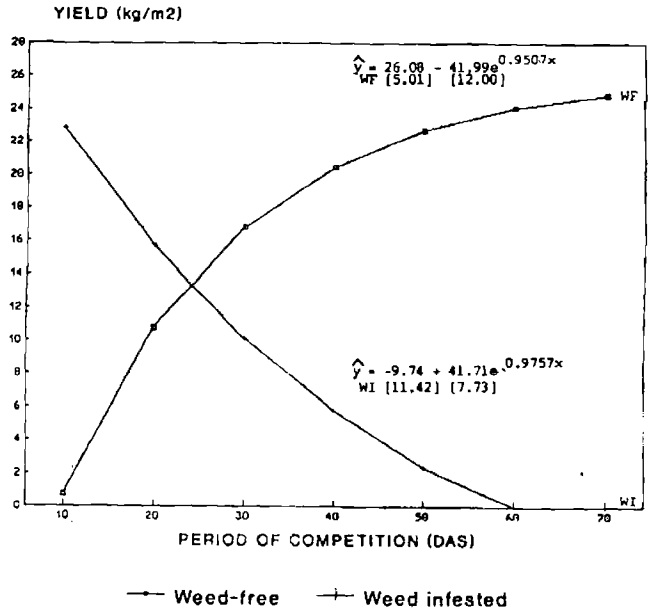

Fig. 2. The effects of varying periods of weed interference on onion yield.

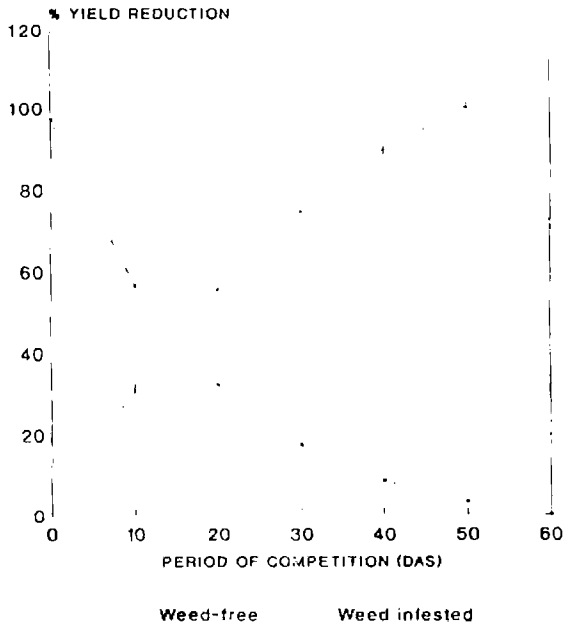

Fig. 3. Effects of varying period of weed interference on % marketable on onion yield reduction.

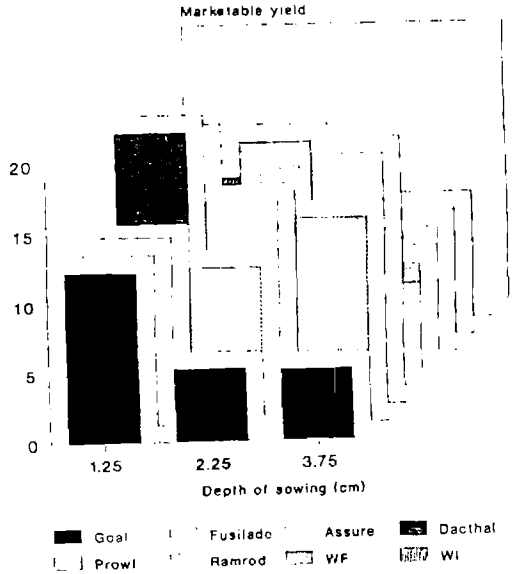

Fig. 4. The effect of depth of sowing and weed management on onion yield (kg/m2)

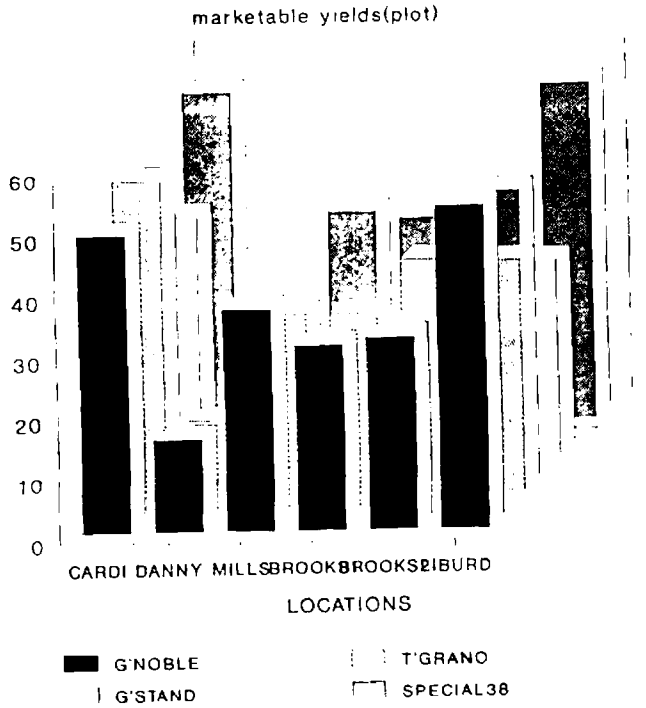

Fig. 5. Marketable yield of onions for six farms in St. Kitts/Nevis.

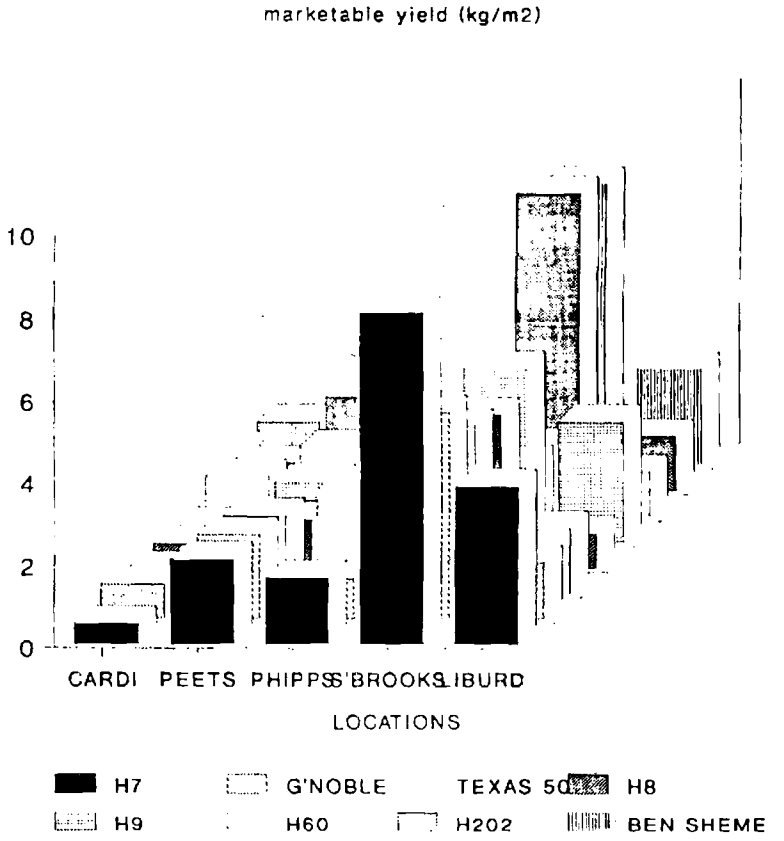

Fig. 6. Marketable yield of onion for five farms in St. Kitts/Nevis.

ENTOMOPHAGOUS SPIDERS AS AGENTS FOR BIOLOGICAL CONTROL OF PESTS OF COLE CROPS IN JAMAICA

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ABSTRACT

Fifteen species of spider belonging to eight different families have been found feeding voraciously on larvae of diamondback moths (DBM), *Plutella xylostella*; cabbage looper (CL), *Trichoplusia ni*; army-worms (AW's), *Spodoptera latifascia*; a pyralid (P), *Pilemia periusalis* and an unidentified noctuid (N). The population of spiders remained constant in unsprayed fields, ranging from 2/m^2 of *L. atlantica*, 4/m^2 of *L. fusca* to 0.08/m^2 of others. The spiders were generally most susceptible to diazinon > diaphenthiuron > prophenophos sprays. The spiders showed no preference for the host larvae in multiple-host species diet. Feeding activity that was generally cyclic-intense feeding for a couple days was followed by a similar period of little feeding. The spiders could consume daily about 0.8 to 18.3, 0.1 to 1.7 or 0.1 to 1.7 mature larvae of DBM, CL or AW, respectively. Spraying with prophenophos, diazinon and diaphenthiuron reduced the field population of spiders by 43 to 82%, 80 to 100% and 55 to 97%, respectively.

INTRODUCTION

Potentials of biological control as an adjunct to integrated management of vegetable pests has never been explored in Jamaica, though Forbes and Mansingh (1988) had reported high incidences of parasitism in the field populations of diamondback moths (DBM), *Plutella xylostella* (L.). In fact, they recorded the larval parasites, *Diadegma insulare* (Cresson) and a larval-pupal parasite, *Oomyzus* (=*Tetrastichus*) *sokolowskii* (Kurdj.) and a new species of a hyperparasite of *Diadegma*, *Spilochalcis* sp. for the first time in the Caribbean. Later, Alam (1992) found two more species of DBM parasites and three new species of hyperparasites in the island. Furthermore, three exotic species of parasites, *Cotesia plutellae* (Kurdj.), *Trichospilus diatraeae* C. & M. and *O. sokolowskii*, which were introduced during 1988-89 were found fully established in Jamaica.

Jamaica is also rich in other natural enemies of crucifer pests- eight species of insect predators, viz. *Coleomegilla maculata* (DeGeer), *Cycloneda sanguinea* (L.), *Hippodamia convergens* Guerin (Coccinellidae), *Belonuchus gagates* (Erichson) (Staphylinidae), *Toxomerus dispar* (F.),*Toxomerus watsoni* (Curran) and *Pseudodoros clavatus* (F.) (Syrphidae), *Ceraeochrysa claveri* Navas (Chrysopidae) and three species of parasitic fungi, *Beauveria bassiana*, *Hirsutella* sp. and *Paecilomyces fumosoroseus* (Alam,1992).

Further surveys of vegetable growing areas in Jamaica revealed the presence of 15 species of spiders predating on crucifer pests. The present report explores their population fluctuations, biological control potential and susceptibility to pesticides.

MATERIAL AND METHODS

Collections of spiders

Spiders were collected from unsprayed experimental cabbage fields at Douglas Castle in central Jamaican (elevation, 610 m), Castle Kelly (elevation, 457 m), and Bodles Agricultural Experimental

Station (elevation 18 m), during 1992-94. Ground spiders were collected by disturbing the leaf litter in the field, orb weavers from either webs or the cabbage leaves and the jumping and crab spiders from the ground and cabbage plants. These spiders were directed gently into individual glass/plastic vials (2.5x10 cm) with a strip of cabbage leaf. The spiders were identified by Dr. G.B. Edwards (Curator, Arachnida and Myriopods, Florida State Collection of Arthropods, Division of Plant Industry, P.O. Box 1269, Gainesville, Florida 32602).

Population fluctuations

Populations of spiders in two unsprayed cabbage fields were recorded at four weekly intervals of three successive crops, between May 1993 and February 1994, at Douglas Castle. Fields were divided into the peripheral and middle zones and each zone was further subdivided into five randomized 1 m^2 blocks for sampling populations.

Food consumption

The host preferences, the amount of food consumed and the patterns of food consumption by the spiders were studied by feeding all but four species individually in vials on single host species diet comprising of mature (last two instars) larvae of *P. xylostella*, *T. ni*,*S. latifascia*, *P. periusalis* and an unidentified noctuid species, or on a multiple-host species diet, which included the larvae of the host species. *Hentzia* sp., *C. pulcherrima*, *Habronathus* sp., *Oxyopes* sp. and *T. gonygaster*, were always fed on the first two instars of the host larvae as they could not handle and feed on larger larvae.

Each spider was provided with a pre-weighed diet of the host larvae, which was replaced every 24 hours for one week. The unconsumed larvae were weighed, the amount consumed during the preceding 24 hours was estimated.

The daily pattern of food consumption was studied on five of the most common species of spiders found in the field. Five individuals of each species were provided daily with pre-weighed diet of multiple host species. The experiments were conducted for 36 to 80 days, depending upon the survival of the species under captivity.

A biological control index (BCI) of each species was calculated by multiplying the mean population/ m^2 by the mean number of larvae of DBM consumed by the spider per day.

Effect of Insecticides

Preliminary observations in various fields/farms, which were regularly sprayed with insecticides, indicated very low populations of the most predominant species of spiders. A study was therefore undertaken to evaluate the effect of selecron (Profenofos)EC 500 at the rate of 3.1 mL/L; basudin (Diazinon) EC 60, at the rate of 0.5l/ha; and pegasus (Phio urca) SC 500, at the rate of 3.7-5.0 l/ha in fields (about 0.5 ha) which were sprayed by farmers using a knapsack sprayer. Unsprayed fields were adjacent to each sprayed field. The treated and control fields were randomly divided into five 1 m^2 plots and the population of spiders counted one week after spraying.

RESULTS AND DISCUSSION

Spider species

Fifteen species of spiders belonging to eight different families (Table 1) are quite widespread in Jamaica, as they were recorded from each of the three cabbage growing areas of the island. The orb-weaver (Araneidae) was the largest family with three species, followed by Lycosidae, Oxyopidae, Argiopidae, Theridiidae and Salticidae, with two species each, and Heterapodidae and Tetragnathidae,

with one species each. All these species are widespread also in the tropics and neotropics, including southern USA and Europe (Levi and Levi, 1990).

Population fluctuation

All but four species of spiders were always found in the study areas, distributed evenly in the peripheral and middle zones of the cabbage fields (Table 2). *L. atlantica, L. fusca, T. gonygaster, A. trifasciata* and *Habronathus* sp. were the most abundant species with a mean monthly population of 2.0, 2.0. 1.2, 1.03 and 1.02 spiders/m^2. The mean monthly populations of seven other species ranged between 0.42 and 0.021 spiders/m^2. Among the least abundant species was *L. regnyi* (0.19/ m^2), *N. neotheis* (0.15/m^2), *G. canceriformis* (0.12/m^2) and *H. venatoria* (0.06/m^2). The last two species were conspicuous by their absence during post-rainy seasons, particularly during winter months. Generally the population of spiders, particularly the orb-weavers, in the field depended upon atmospheric dynamics (Greenstone et al., 1991), vegetation, (MacArthur, 1969, Pianka, 1966), and the host population (Greenstone, 1984). Both these factors were constant in our study fields to account for difference in the populations of different species. Greenstone et al (1987) had found a correlation between mass of ballooning spiders and their frequency distribution in Missouri (USA) and New South wales (Australia); more than half of the spiders caught were 0.6mg and 85 to 94% were <1 mg in weight. Our data in Table 3 reveals no general mass frequency relationship. The heaviest spider, *P. viridens* and the lightest ones (*Hentzia* sp. and *Oxyopes* sp.) were always the least abundant species. Likewise, the moderately heavy species, *L. fusca* (0.15 g) and *L. atlantica* (0.01 g) were the most abundant spiders (2/m^2), while *A. argentata* with smaller weight (0.11 g) was the least (0.2/m^2) abundant species.

The population densities of different species may be a phenomena of preying modes, and weight of the spider. Indeed, among the orb-weavers, *A. argentata, A. trifasciata* and *T. gonygaster*, there was no overall correlation between spider weight and population (Table 3). Among jumping and hunting spiders, however, the heaviest (*P. viridens*) and the lightest (*Oxyopes* sp. and *Hentzia* sp.) appear to have the least, while the medium sized (0.01 and 0.15 g) have the maximum advantage in frequency distribution. It may be pointed out that because spiders have metabolic and anatomical adaptation (Greenstone, 1978; Greenstone and Bennett, 1964) which reduces their energy requirements and buffer them against energy availability, "the marginal scare resources become adequate" (MacArthur, 1969) and influence their frequency distribution.

The orb-weaver population is dependent upon structural diversity of the habitats, which is required by spiders for physical support (MacArthur and MacArthur, 1969). Web spider density is highly correlated with vegetation and tip height diversity; prey availability is not a significant factor (Greenstone, 1984).

Food preferences and consumption

The spiders showed no preference when fed on multiple host diet. Apparently, the nearness and activity of the larvae prompted response from the predators. The spiders were more interested in satisfying their appetite and consuming a certain amount of food (Table 4), rather than discriminating among the host species.

It is pertinent to note that some spiders do exercise preferential feeding on insects, depending upon developmental stage, size and odor of the prey. Two species of Lycosidae feed preferentially on insects in California (Greenstone, 1980). Several web-spider species were found to consume Ephemeropteron and Dipteron, which were 6 and 5 mm in length, but on other insects which were less than 4 mm in length (Greenstone, 1984). Only < 2 mm long Orthoptera and Thysanoptera could be consumed.

The amounts of food consumed varied greatly among the spiders, the most voracious feeders, *H. venatoria, L. atlantica, P. viridens* and *L. fusca*, were consuming about 0.165, 0.137, 0.126, and

0.124 g of food/day respectively. If fed on single species diet, the number of the last two instar larvae of DBM consumed by the four species of spiders would range from 18.3 to 13.8, while only about 0.69 to 0.52 g of the larger noctuid larvae would be eaten (Table 4). The other seven species could consume from about 0.8 to 6.7 DBM larvae/day, but only parts of other larvae. Muckenfus et al (1992) had reported increased consumption of DBM larvae by the spider *Pardosa milvinna* (Hentz), when host density increased from 1 to 8 larvae/cage and with time. In our in vitro studies, no such correlation was evident as the food supplied was always more than the ability of the spiders to consume. Greenstone (1978) demonstrated that free living wolf spider tends to prey on species in proportion, which optimizes the proportions of essential amino acids they provide in the diet, and suggested that this could account for the differences in the amount of different prey species consumed by the spiders. This is obvious that all the host larvae satisfied equally the amino acid and other nutritional requirements of the spiders.

In Jamaica an interesting correlation between the weight of the spider and the weight of the food consumed is presented in Table 5. Among the four species which could prey upon only first and second instar larvae, *Habronathus* sp. was the most voracious followed by *Hentzia* sp., *C. pulcherrima* and *T. gonygaster*, respectively.

Detailed studies on the pattern of food consumed by six different spiders, ranging from most to least voracious species revealed that (1) intense feeding activity for a day or two was usually followed by a couple of days of significantly ($p>0.01$) low levels of food consumption, and (2) some species, e.g., *L. atlantica* (Fig. 1), *H. venatoria* (Fig. 2), *P. viridens* (Fig.3), *L. fusca* (Fig.4) and *Habronathus* sp. (Fig. 5) showed distinct periods of intense and moderate feeding, and (3) the least voracious, *Hentzia* sp. consumed at uniform level, showing no significant difference ($P>0.01$) during most of its life (Fig. 6).

Apparently the feeding behavior of the spiders has evolved foraging and physiological adaptation for overcoming uncertainty of adequate food availability in their habitat. Like insects during dormancy, the spiders depress metabolic rates below resting levels during periods of starvation (Anderson, 1978; Humphreys, 1977). This metabolic variability has a net effect on energy loss for spiders than for other animals of their size and tropic position (Greenstone, 1978). Furthermore, spiders tend to optimize acquisition of nutrients, rather than maximize energy intakes (Greenstone, 1979). The pattern of fluctuations in the intake of food by the Jamaican spiders may be an inherent, environmentally induced adaptive strategy for the optimization of food intakes.

Effect of insecticides

Selecron, pegasus and basudin sprays reduced the field populations of seven species of spiders by 43 to 82 %, 82 to 100% and 55 to 97 % respectively, depending upon the species of spiders and the insecticides (Fig. 7, Table 6). The reduction in the predator populations resulted in significant ($p>0.05$) build up of the DBM, CL, AW populations (Table 4). A similar increase in DBM population in pyrethroid treated plots was reported by Muckenfuss et al., (1992) and attributed to the mortality of *Diadegma insulare* (Cresson) and *P. milvinna* due to the insecticide.

Biological Control Potential

Spiders with phenomenal densities are the most constant components of our environmental complex (Dondale, 1970). These features "would make spiders the most important group of insectivore in some terrestrial habitat" (Greenstone and Bennett, 1980). Indeed our data endorse these statements, as far as Jamaican cabbage fields are concerned.

L. atlantica with biological control potential index (BCI) of 336 is the most promising natural enemy of DBM, followed far behind by *L. fusca* (27.6) > *Habronathus* sp. (4.8) > *P. viridens* (4.3) > *A. trifasciata* (1.5) and others (0.13 - 1.2). However, the use of insecticides would nullify the advantage of the natural enemies. Appropriately timed augmentation of field population of spiders

with a greenhouse cultured population aught to eliminate the use of insecticides. Further investigations on the colonization of insecticide-treated cabbage fields by the spiders would be required for developing an integrated management strategy of the cabbage pests.

Table 1: Species of spiders collected from fields in three cabbage growing areas of Jamaica.

Common Name	Family	species
Orb-weavers	Araneidae	*Eriophora* sp.
		Gasteracantha cancerifórmis (L.)
		Neoscona neothcis (Petrunt.)
	Argiopidae	*Argiope argentata* (Fab.)
		Argiope trifasciata (Forskal)
Wolf/Ground spiders	Lycosidae	*Lycosa atlantica* Marx
		Lycosa fusca (Keyserling)
Lynx/Hunting spiders	Oxyopidae	*Oxyopes* sp. *lineatipes*? (Koch)
		Peucetia viridens (Hentz.)
Jumping Spiders	Salticidae	*Habronathus* sp. Sensu Latu
		Hentzia sp. *vittata*? (Keyserling)
Combfooted or Cobweb spiders	Theridiidae	*Chrysso pulcherrima* Malls Leitao
		Theridula gonygaster (Simon)
Hunting Spider	Heteropodidae	*Heteropoda venatoria* (L.)
Four Jawed Spiders	Tetragnathidae	*Leucauges regnyi* (Simon)

Table 2: Population of different species of adult spiders/m²Douglas Castle, Jamaica, between May 1994 and February 1994.

	Population of spiders/m² at each month in 1993 and 1994.									
Species	M	J	J	A	S	O	N	D	J	F
L. atlantica	2.4	2.1	1.8	1.2	1.9	2.2	1.7	2.9	3.2	1.6
L. fusca	2.3	1.6	1.2	1.3	1.7	1.8	1.8	2.9	3.1	2.1
T. gonygaster	1.2	1.4	1.1	0.7	1.0	1.4	1.1	1.3	1.4	1.2
A. trifasciata	0.8	0.7	0.8	0.5	0.9	1.0	0.7	1.0	1.6	2.3
Habronathussp.	1.0	0.9	0.6	0.7	1.6	1.2	1.0	1.1	1.2	0.9
C. pulcherrima	0.3	0.4	0.4	0.3	0.4	0.4	0.5	0.5	0.5	0.5
Hentzia sp.	0.4	0.4	0.2	0.3	0.3	0.4	0.4	0.5	0.4	0.6
L. regnyi	0.4	0.2	0.2	0.2	0.1	0.3	0	0.3	0.1	0.1
P. viridens	0.2	0.1	0.2	0.1	0.1	0.1	0.5	0.4	0.2	1.2
Oxyopes sp.	0.4	0.4	0.5	0.1	0.3	0.1	0.3	0.1	0.5	0.3
Eriophora sp.	0.2	0.4	0.3	0.3	0.2	0.4	0.2	0.1	0.1	0.3
A. argentata	0.3	0.2	0.2	0.2	0.1	0.2	0.1	0.1	0.3	0.4
N. neothcis	0.4	0.1	0.2	0.1	0.1	0.2	0.1	0	0.2	0.1
G. canceriformis	0.3	0.3	0.1	0	0.3	0.1	0	0	0	0
H. venatoria	0.1	0.1	0.1	0.1	0.1	0.1	0	0	0	0

Table 3: Spider weight and population.

Species	Foraging Mode	Wt.(g) ±SE	Population/m²
P. viridens	Hunting	0.30 ±0.024	0.3
L. fusca	Hunting	0.15 ±0.016	2.0
A. argentata	Orb-weaver	0.11 ±0.016	0.2
L. atlantica	Hunting	0.10 ±0.027	2.0
A. trifasciata	Orb-weaver	0.03 ±0.004	1.0
Habronathus sp.	Jumping	0.01 ±0.001	1.0
Oxyopes sp.	Hunting	0.007±0.0007	0.3
Hentzia sp.	Jumping	0.004±0.0002	0.4
T. gonygaster	Orb-weaver	0.004±0.0002	1.2

Table 4: Estimated consumption of different species of host larvae by various species of spiders in Jamaica in captivity.

Species	Estimated numbers of different[1] species[2] of larvae consumed/spider/day					
	Consumption (g)±SE	DBM	CL	AW	P	N
H. venatoria	0.17±0.02	18.3±1.0	1.7±0.01	1.7±0.09	2.2±0.004	0.7±0.002
L. atlantica	0.14±0.01	15.2±0.6	1.3±0.01	1.4±0.06	1.8±0.003	0.6±0.003
P. viridens	0.13±0.01	14.0±0.4	1.2±0.01	1.3±0.1	1.7±0.001	0.5±0.001
L. fusca	0.12±0.02	13.8±0.5	1.2±0.02	1.3±0.12	1.6±0.01	0.5±0.001
A. argentata	0.06±0.001	6.7±0.1	0.6±0.003	0.6±0.02	0.8±0.003	0.3±0.002
A. trifasciata	0.06±0.002	6.4±0.2	0.6±0.005	0.6±0.02	0.8±0.002	0.2±0.004
Habronathus sp.*	0.04±0.003	4.0±0.06	0.4±0.01	0.4±0.06	0.5±0.001	0.2±0.004
Hentzia sp.*	0.03±0.002	3.1±0.06	0.3±0.001	0.3±0.05	0.4±0.001	0.00±0.001
*C.pulcherrima**	0.01±0.0001	1.4±0.03	0.1±0.004	0.1±0.02	0.2±0.02	0.00±0.00
Eriophora sp.	0.01±0.0004	1.6±0.1	0.1±0.004	0.2±0.07	0.2±0.001	0.06±0.002
G.canceriformis	0.01±0.0001	1.1±0.01	0.1±0.0002	0.1±0.02	0.13±0.02	0.04±0.001
*T. gonygaster**	0.008±0.002	0.9±0.06	0.1±0.02	0.1±0.01	0.1±0.01	0.03±0.00
L. regnyi	0.008±0.0001	0.9±0.04	0.1±0.01	0.1±0.01	0.1±0.001	0.03±0.001
N. neothecis	0.008±0.0005	0.9±0.01	0.1±0.0003	0.1±0.01	0.1±0.002	0.03±0.001
Oxyopes sp.*	0.007±0.004	0.8±0.02	0.1±0.03	0.1±0.04	0.09±0.001	0.02±0.001

1. DBM = *Plutella xylostella*; CL = *Trichoplusia ni*; AW = *Spodoptera latifascia*; P = *Pilemia periusalis*; N = Unidentified noctuid.
2. All spiders were fed on the last two instars of host larvae except those with * (five species) which could consume only the first two instars.

Table 5: Relationship between spider weight and weight of food consumed.

Species	Spider's weight (g)	Food consumed(g/g spider wt.)
P. viridens	0.30	0.42
L. fusca	0.15	0.82
A. argentata	0.11	0.54
L. atlantica	0.10	1.37
A. trifasciata	0.03	1.93
Habronathus sp.	0.01	3.60
Oxyopes sp.	0.007	1.00
Hentzia sp.	0.004	7.00
T. gonygaster	0.004	2.00

Spider weight is related to the inverse of the food consumption by the following equation.
1/food = 0.437 + 6.553
(SE= 0.394 1.404)

Table 6: Effect of insecticide sprays on the population of spiders and cabbage pests.

Species	Population mean ± SE Unsprayed	Sclecron	Pegasus	Basudin
Predators				
L. atlantica	8.62 ± 2.44	1.52* ± 0.69	0.89* ± 0.55	1.72 ± 2.01
L. fusca	7.56 ± 1.70	1.89* ± 0.75	1.51* ± 0.75	0.001 ± 0.03
T. gonysaster	7.33 ± 0.90	2.10* ± 0.63	1.16 ± 0.70	3.33 ± 1.82
H. vittata	2.66 ± 0.54	0.47* ± 0.28	0.001 ± 0.02	1.14 ± 0.73
A. trifasciata	1.77 ± 0.45	1.01 ± 0.60	0.001 ± 0.005	0.59 ± 0.45
Oxyopes sp.	1.26 ± 0.42	0.42 ± 0.20	0.14 ± 0.12	0.05 ± 0.06
Habronathus sp.	0.69 ± 0.37	0.23 ± 0 14	0.08 ± 0.08	0.02 ± 0.04
Pests				
P. xylostella	3.1 ± 0.37	4.3 ± 0.58	7.4* ± 1.22	6.2* ± 1.11
T. ni	1.26 ± 0.23	2.4* ± 0.43	2.8* ± 0.75	2.0 ± 0.63
S. latifascia	0.7 ± 0.17	0.8 ± 0.24	1.4 ± 0.53	0.6 ± 0.35

* significantly ($p < 0.05$) different with the unsprayed plots.

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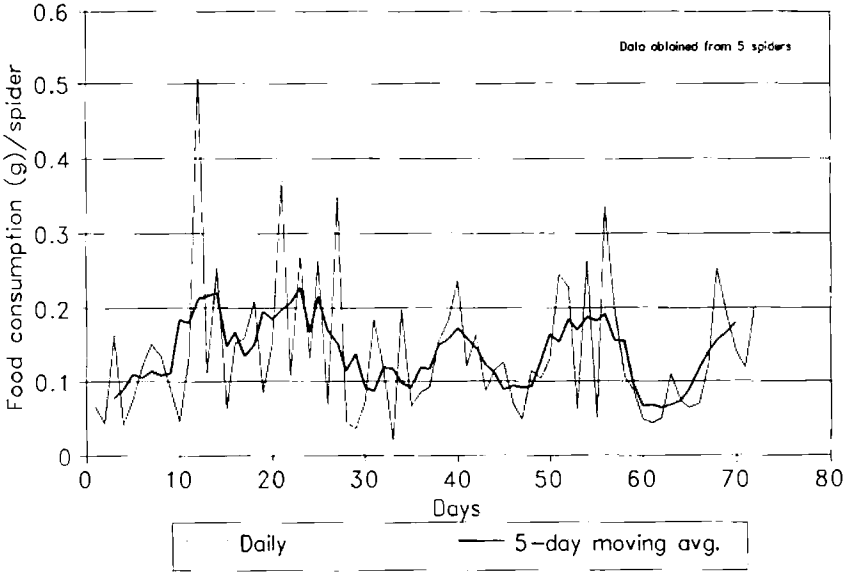

Fig. 1: Weight (g) of host larvae eaten/day and 5-day moving average by Lycosa atlantica

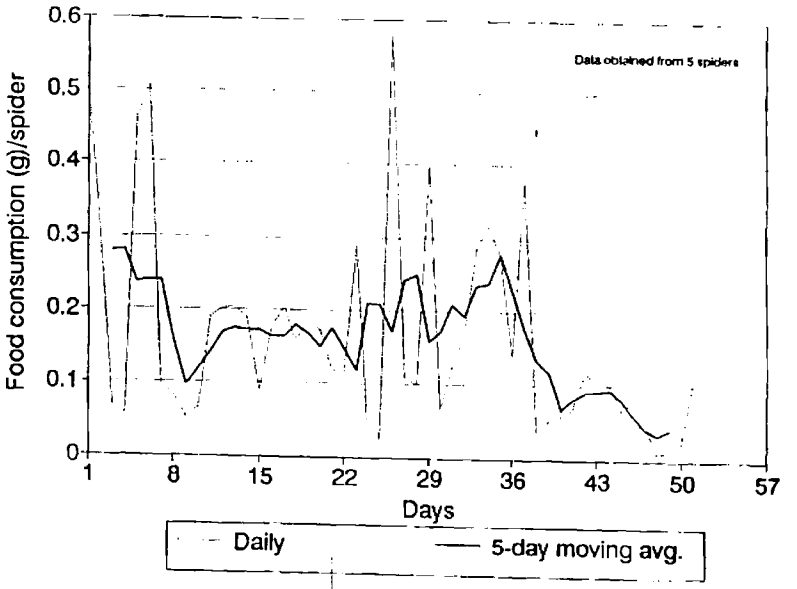

Fig. 2: Weight (g) of host larvae eaten/day and 5-day moving average by Heteropoda venatoria

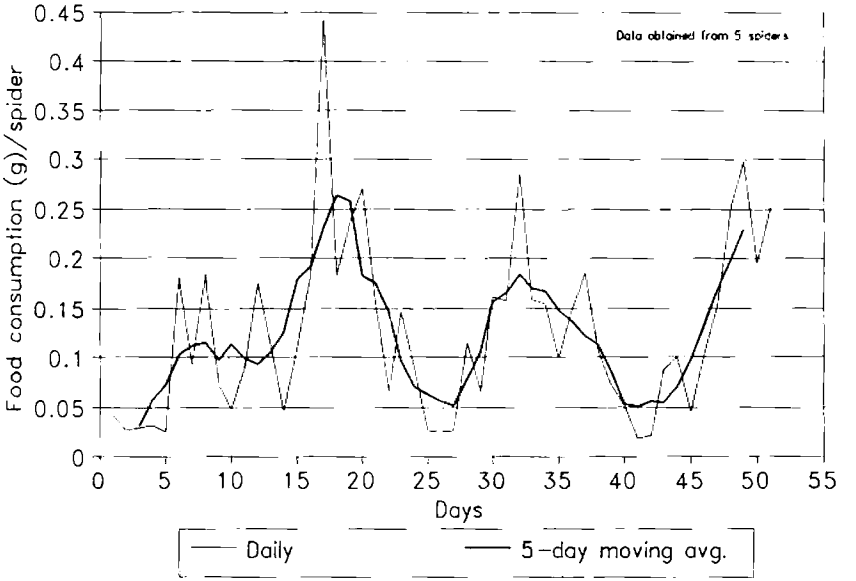

Fig. 3: Weight (g) of host alrave eaten/day and 5-day moving average by Peucetia viridans

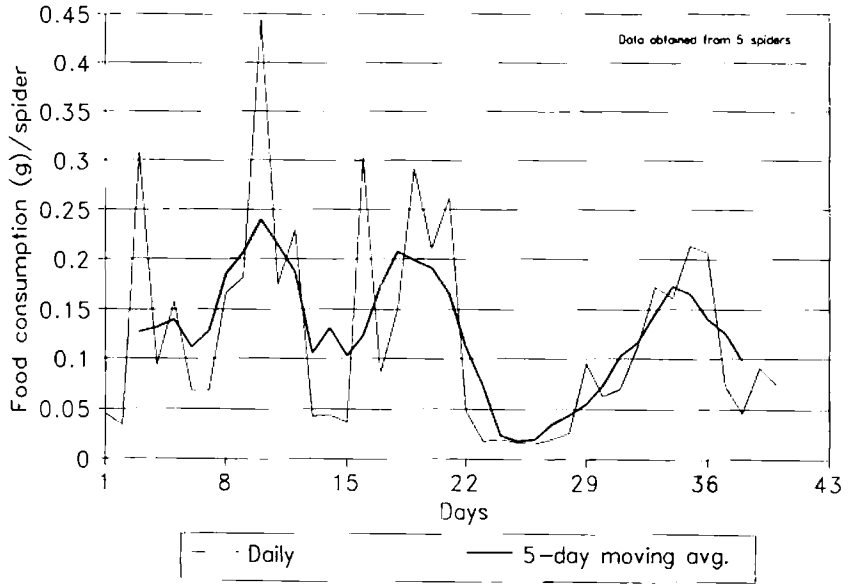

Fig. 4: Weight (g) of host larvoe eaten/day and 5-day moving average by Lycosa fusca

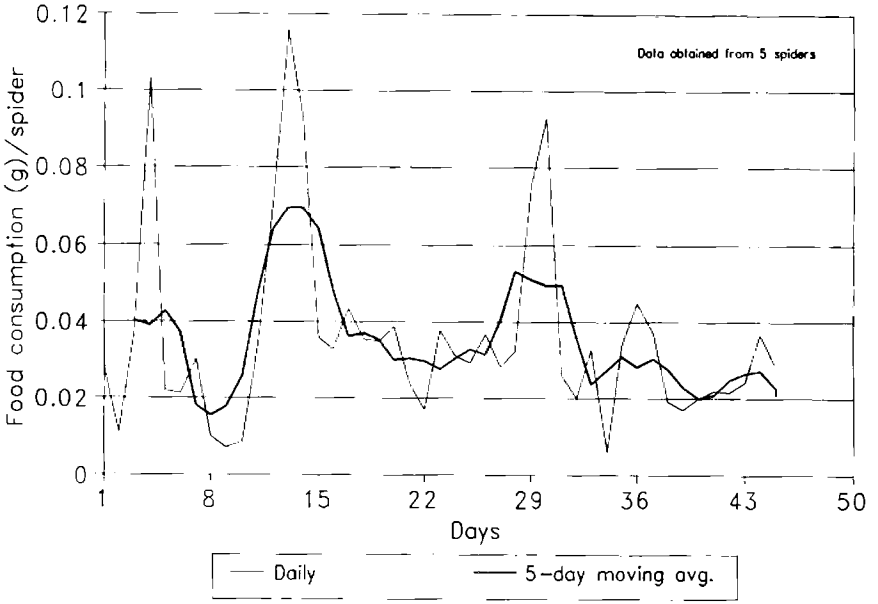

Fig. 5: Weight (g) of host larvae eaten/day and 5-day moving average by Habronathus sp.

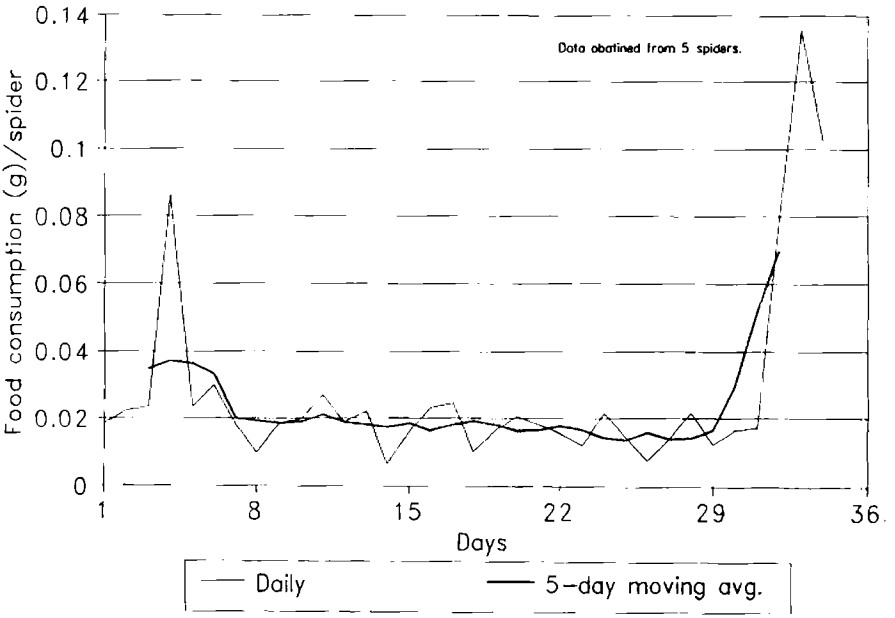

Fig. 6: Weight (g) of host larvae eaten/day and 5-day moving average by Hentzia sp. vittata?

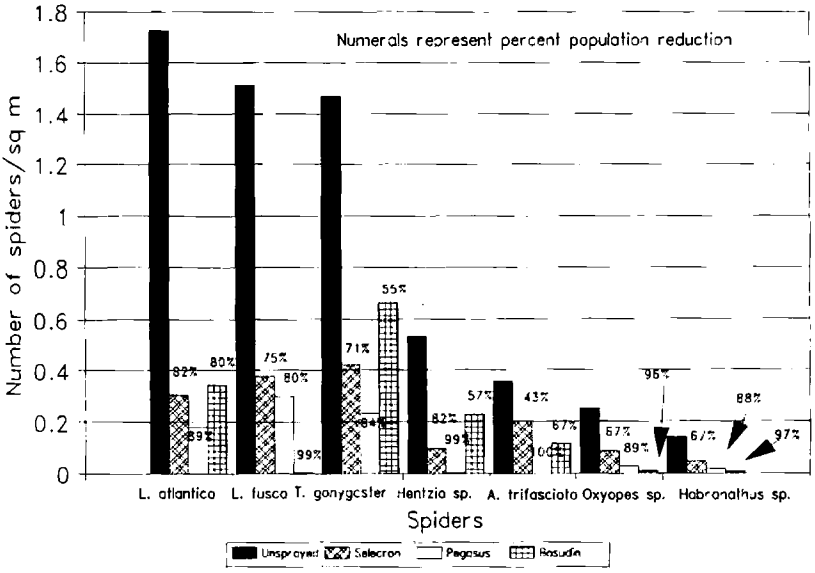

Fig. 7: Population of different species of spiders in cabbage fields, one week after spraying with three insecticides

TOXOPTERA CITRICIDUS,(*HOMOPTERA APHIDIDAE*) A VECTOR OF CITRUS TRISTEZA VIRUS (CTV) IN GUADELOUPE DISTRIBUTION AND DISEASE INVESTIGATION

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ABSTRACT

In Guadeloupe the most efficient vector of citrusTristeza virus (CTV), *Toxoptera citricidus*, was discovered at the end of 1991. The distribution of this vector was determined based on surveys made in each locality of the archipelago. At the same time, the search for Tristeza disease by an ELISA test was undertaken and results were all negative. From now on, regular control of all the nurseries, in order to deliver only healthy material, and the use of resistant rootstock are highly recommended. An integrated control program against *T. citricidus* must also be started. Finally, it is necessary to continue the watch for citrus Tristeza virus (CTV) on a regular basis, so as to detect it as soon as it appears and take the immediate and necessary measures. Finally the general distribution of *T. citricidus* and CTV in the Caribbean area is presented.

RESUMEN

En Guadalupe, el vector el mas eficiente de la Tristeza, *Toxoptera citricidus* , fue descubierto en el fin del ano 1991. Prospecciones efectuadas en todos los municipios del pais permitieron establecer un mapa preciso de la distribucion de este vector. Al mismo tiempo, la busqueda de la Tristeza (por el test ELISA) fine emprendida y todos estos tests se mostraron negativos. Desde ahora, una inspeccion regular de todos los viveros para proporcionar solamente material sano y el uso de patrones de injerto resistentes para las nuevas plantaciones son medidas que hay que aconsejar. Una lucha racional debe tambien se emprendida contra *T. citricidus* Por ultimo, la busqueda de la Tristeza debe ser seguida regularmente para detectar su aparicion y tomar en seguida las medidas necesarias. Finalmente se presenta la distribucion general de T. citricidus y del Tristeza es presentada.

INTRODUCTION

In Guadeloupe, five species of aphids one of which appeared very recently, attack citrus. Collections made between 1985 and mid-1991 found *Aphis gossypii* Glover (most common), *Aphis spiraecola* Patch (= *A. citricola* Van der Goot) and *Toxoptera aurantii* (Boyer de Fonscolombe) (very common), and *Aphis craccivora* Koch (least common). *Toxoptera citricidus* (Kirkaldy) was only discovered at the end of 1991 (Leclant et al. 1992a, Etienne et al. 1992b). Until then, it had been found only in Trinidad for the Caribbean Archipelago. (Anonymous 1961). This aphid is found mainly on Rutaceae and develops primarily on young citrus shoots. This differentiates it from other species found on citrus, most of which are polyphagous. Apart from the direct damage

it can cause, *T. citricidus* is also the principal vector of Citrus Tristeza virus (CTV). This disease is particularly serious and is dreaded in citrus growing countries. Throughout many countries e.g., Argentina and Brazil millions of trees have already been destroyed by CTV (Aubert et al. 1992). According to Leclant et al. (1992) it mainly affects citrus that have been grafted onto sour orange because of an incompatibility problem concerning the graft. In limes and grapefruits, trees appear scraggy often associated with stem pitting. Finally, particularly virulent strains can provoke growth problems in orange and tangerine trees which no longer produce marketable fruit. Shortly after *T. citricidus* was discovered in Guadeloupe, an investigation of this aphid was conducted, to determine its distribution on the island. Simultaneously, the young infested citrus shoots were kept and used to sample for CTV (using ELISA tests). Knowledge of the phytosanitary situation of this disease in Guadeloupe, is needed to answer questions about how the vector is distributed and where the disease is located. This information would help to develop methods for delaying or limiting its spread.

DISTRIBUTION OF *T. CITRICIDUS* IN GUADELOUPE

Stroyan (1961) noted 7 species of aphids that are most frequently found on citrus and indicated which keys are needed to identify them. Six of these species are found in Guadeloupe; among them is Myzus persicae (Sulzer), which has not been found on citrus, but is found on other vegetables.

Among the five species found on citrus in Guadeloupe, *T. citricidus* is undoubtedly the most dangerous because of its ability to transmit the virus. It is often confused with *T. aurantii* under the following common name black citrus aphid. But a clear identification of these 2 species is absolutely necessary in order to draw an accurate map of the distribution of this chief vector of CTV.

Diagnosis of 2 species of Toxoptera

The 2 species of Toxoptera collected on citrus are shiny brown to brownish black when adult and paler brown when immature. T. citricidus is an aphid generally much larger than *T. aurantii*. Winged and apterous forms of the two species are identified as follows (Fig. 1).

- Median vein with 2 branches, pterostigma black, antennae articles III, IV, V lower part pale and apex darkened to winged and apterous..... .....*T. aurantii*

- Median vein with 3 branches, pterostigma lightly pigmented (yellowish for the living insect) antennae with article III black for winged and entirely pale for apterous..... .T. *citricidus*

Figure 2 shows that surveys have been carried out in the territory of the 26 towns of Guadeloupe and that prompt controls have been established in some islands of the archipelago. The black citrus aphids have been sought on citrus with young shoots because this is where these insects develop.

The importance in the *T. citricidus* populations varies considerably throughout the island.Populations of the aphid are found everywhere on Basse Terre, except in the Deshaies area. On Grande-Terre the aphid has only been found in 5 areas in isolated colonies, each of them consisting of a limited number of individuals. In the N.E. region, which is much drier and lacks orchards, the surveys were made on isolated trees around dwellings. No *T. citricidus* were collected from the 165 trees inspected in this region. Only 10 % of the trees had *A. gossypii, A. spiraecola* and *T. aurantii aphids.*

T. citricidus is typically found in humid tropical areas. Observations on its present distribution confirm this. It was very common in the humid areas of Basse-Terre, but only a few colonies were

found in Grande-Terre and none in the drier zones.

INVESTIGATION FOR CITRUS TRISTEZA VIRUS (CTV)

Aphid vectors

Research on aphids which are vectors of CTV (Roistacher & Bar-Joseph, 1987) has indicated that *T. citricidus* is the most efficient vector of this disease. Moreover, it is the only aphid species which is almost exclusively limited to citrus whereas other species which are polyphagous may be found on this crop intermittantly. It has been shown that *A. gossypii* can transmit CTV, but less efficiently. *A. spiraecola* and *T. aurantii* were of minor importance as vector of CTV. One single *T. citricidus* can transmit the disease very rapidly (less than an hour), whereas it takes a great number of individuals of other aphid species to transmit the disease. *T. citricidus* and *A. gossypii* transmit CTV in a semi persistent way. The length of time needed to acquire the virus can be very short (less than one hour) but 24 hours seem to be the optimal time. After 24 hours, it loses its ability to transmit the virus provided individuals do not feed on CTV infected plants.

Citrus Tristeza virus research

Although CTV can spread without any vectors, by movement of infected plant materials, it is obvious that the presence of *T. citricidus* considerably increases the likelihood of disease spread. Different techniques have been developed to detect this disease (Rocha Pena & Lee, 1991). Among these, an ELISA test gives quick results (less than 24 hours) and was therefore chosen for CTV detection.

A total of 655 ELISA tests were done in 1992 and 1993. These tests were carried out from samples collected either from isolated trees infested by *T. citricidus* or from plant material (nurseries) multiplied and prepared for new tree fields. All these samples were tested with the dDAS-ELISA test (Double Antibody Sandwich Direct, prepared by SANOFI) and they all stood negative.

CONCLUSION

In Guadeloupe, the study of the T. citricidus distribution, which was started as soon as it was discovered, showed that this aphid had colonized the whole of the island except for the North and the East where the climate is dry. At the same time, a search for CTV detection by means of the ELISA test was started in all the zones with important populations of *T. citricidus* and all the tests proved negative. Such tests will have to be done periodically so as to detect and destroy areas of possible infestation.

From now on, the use of resistant understock to develop new plantations, and regular control of existing nurseries is recommended. It has been proven (Bar-Joseph and et al., 1989) that the scattering of CTV by infected material is one of the major causes of the spread of this disease. These measures must be accompanied by an integrated control against the main vector *T. citricidus*. This should not only preserve the aphid's natural enemies, but also avoid other possible citrus pests because of a break in the balance.

Generally, the surveys undertaken in the Caribbean area have indicated that T. citricidus is present in many islands (Fig 3). It was indeed reported in 1992 in Guadeloupe, Martinique, Saint Lucia, Dominican Republic (Leclant et al, 1992; Etienne et al, 1992b) an in Puerto Rico (Garnsey and Yokomi, 1992) then in 1993 in Saint Kitts (Etienne, unpublished data), in Jamaica (Etienne et al, 1993) and in Cuba (anonymous, 1993). In this area, CTV is presently mentioned only from Trinidad (Barbeau, 1992) and from Puerto Rico (Aubert et al, 1992). In Dominican Republic, though T. citricidus was reported only recently, itseems quite obvious that it has been present in this country for a longtime and in these conditions, the hypothesis was expressed that CTV itself

might be also present in this country (Etienne et al., 1992a). Moreover, that was confirmed during the CFCS meeting held in this country in August 1992 (Abud-Antun, personal comunication).

From a general point of view, *T. citricidus* progresses to the North along two parallel routes. One is central America, with confirmation of its presence in Costa Rica (Voegtlin and Villalobos 1992), and the other, the Caribbean area as indicated in this paper. If it keeps on spreading, other countries such as Mexico and south of Florida could be invaded soon.

ACKNOWLEGEMENTS

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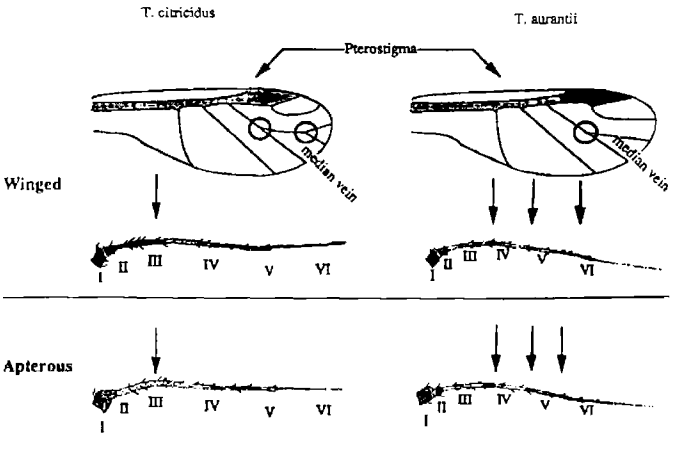

Fig. 1. Main distinguishing characteristics between *T. citricidus* and *T. aurantii*.

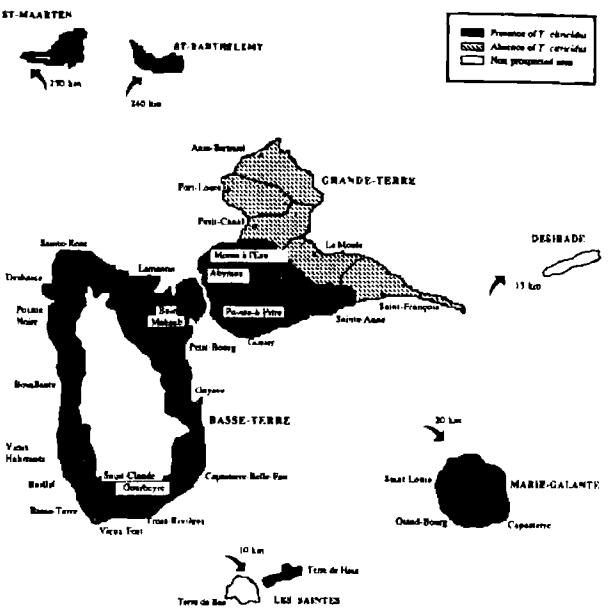

Fig. 2. Map of Guadeloupe archipelago showing the locations of *T. citricidus*

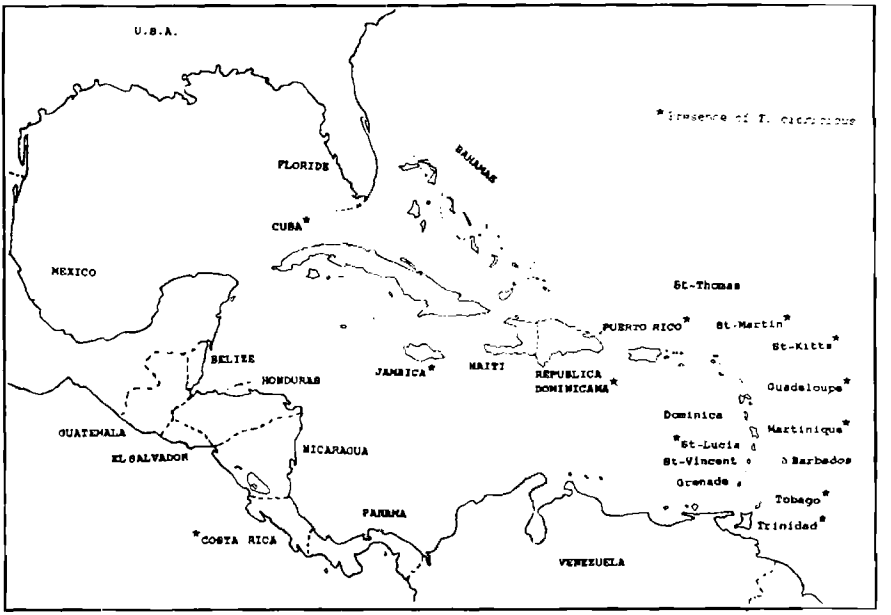

Fig. 3. Geographical distribution of *T. citricidus* in the Caribbean.

CONSERVATION, CHARACTERIZATION AND UTILIZATION OF COCOA GENETIC RESOURCES

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ABSTRACT

The International Cocoa Genebank, Trinidad (ICG,T) is one of two cocoa germplasm collections recognized by the International Plant Genetics Resources Institute (IPGRI). The ICG,T which has approximately 2,500 accessions and encompasses a wide range of germplasm collected in South and Central America and the Caribbean is managed by the Cocoa Research Unit (CRU). Sixteen plants of each accession are planted in a 35 ha site at La Reunion in Trinidad. Characterization of these accessions is underway by recording of morphological, biochemical (isoenzyme and Random Amplification of Polymorphic DNA), disease resistance (*Crinipellis* and *Phytophthora*) and physiological (drought tolerance and rates of photosynthesis) characters. For morphological characterizations 65 botanical attributes of leaf, flower and pod are recorded as recommended by the IPGRI. Research is now underway in an attempt to reduce this number to nineteen. CRU maintains a Quarantine Station in Barbados (where cocoa is not grown), through which incoming and outgoing accessions are quarantined for two years. There are two other quarantine stations in use for cocoa, one at Reading University in the United Kingdom and the other at Montpellier in France, which are also used for the transfer of cocoa materials. After passing through quarantine, these accessions are available to cocoa producing countries throughout the world, where they will be utilized in cocoa breeding programs to produce commercial varieties.

INTRODUCTION

The need for conservation of *Theobroma cacao* (cocoa) genetic resources arises from two causes, firstly the destruction of the Amazon forests which may remove the wild cocoa trees in centres of diversity and secondly the decline in cocoa production along with the introduction of superior clonal lines which may lead to the loss of diversity of fine flavored Trinitario types in the Caribbean.

The International Plant Genetic Resources Institute (IPGRI) formerly the International Board for Plant Genetic Resources) currently recognizes two international centres for cocoa germplasm conservation. These are the Tropical Agricultural Research and Training Center (CATIE) at Turrialba in Costa Rica and the International Cocoa Genebank, Trinidad (ICG,T) at the Cocoa Research Unit (CRU), St. Augustine, Trinidad and Tobago. The CATIE collection holds a valuable collection of Criollo material whereas the CRU collection has been developed mainly from introductions of Forastero from South America and Trinitario collected in the Caribbean.

The basic requirements for conservation of cocoa are a secure system for long-term maintenance of the gene pool; however if this material is to be useful to plant breeders then a reliable means of identification is essential and a knowledge of the occurrence of characters of economic importance is important for the utilization of the material. The ICG,T now holds some 2,500 accessions, and acquisition of new material by collection and exchange is continuing. Thus it is not possible or desirable that the full collection be obtained by every plant breeding program in the various cocoa producing countries. Thus selection of material by individual breeders is greatly facilitated by the characterization of the material in terms of morphology, disease and pest resistance, physiological characters (drought resistance, rates of photosynthesis).

THE INTERNATIONAL COCOA GENEBANK, TRINIDAD (ICG,T)

The ICG,T now comprises some 2,500 accessions of which approximately 2,000 have been established at the University Cocoa Research Station (UCRS) at La Reunion and some 500 are under quarantine (for two years) at the Quarantine Station maintained in Barbados by CRU. Since there is no cocoa in that country the accessions can be grown under natural conditions. The other quarantine stations (at Montpellier in France and Reading in the United Kingdom) have to grow the plants in heated greenhouses in the winter months.

At UCRS the ICG,T is planted on a 35 ha site. Each accession is to be represented by 16 trees as clonal plants derived from rooted cuttings. The site had been a cocoa plantation and the new plantings were made maintaining the original drainage system and can be put on a minimal maintenance basis if the need arises.

CHARACTERIZATION

Morphological Description

The original descriptor list endorsed by IPBGR (now IPGRI) (Anon, 1981) consisted of 65 botanical characters of leaf, flower and pod. The first difficulty that arises is that flowers and pods are not available throughout the year. Thus the data has to be accumulated as and when material is available. The measurements involve linear measurements, color assessments, microscopic measurements such that progress with available resources would be very slow towards the objective of characterizing 2500 accessions. To meet this difficulty research has been conducted at CRU (Bekele, 1991) to produce a concise descriptor list of some 19 characters which would be considered adequate for practical purposes (Appendix I). In addition it is hoped that in the near future data of particular importance to the manufacturer (bean flavor, butterfat content and quality, proportion of shell to nib) would be recorded. The assessment of flavor awaits industry agreed standards which are now under discussion.

The data collected is stored in a computer data base at CRU and also sent to the International Cocoa Germplasm Database (ICGD) held at Reading University in the United Kingdom. To date 199 accessions have been fully characterized with a fewer number having been characterized in terms of leaf, flower and fruit descriptors.

It is expected that the concise description list will be put into use shortly, thus allowing for a much faster rate of description.

BIOCHEMICAL DESCRIPTION

1. Isozyme Analysis

Isozyme analysis offers a system with which a large number of individuals may be rapidly evaluated. Also isozyme descriptors are less likely to be influenced by the environment than morphological characters (Sirju-Charran *et al.*, 1991; Johnson *et al.*, 1991).

Currently acid phosphatase (ACP), malate dehydrogenase (MDH) isocitrate dehydrogenase (IDH), phosphogluco-isonerase (PGI), alcohol dehydrogenase (ADH) and Diaphorase are in use at CRU. It should be noted however that use of these six enzyme systems does not allow complete separation of all accessions tested into individual categories. Thus a combination of isozyme and morphological descriptors may have to be used for identification of each individual.

2. Random application of polymorphic DNA (RAPD)

This technique involves the extraction of DNA and assessment of variability. Studies on this

system were carried out at the Scottish Crops Research Institute (SCRI) in collaboration with CRU (Wilde *et al.*, 1991). Currently CRU is collaborating with CIRAD-CP (France) in refining the system. CIRAD-CP has stationed a molecular biologist (O. Sounigo) at CRU, thus collaboration takes place with their laboratories at Montpeller. Further work is required on this system; reproducibility at individual laboratories seems possible but differences are currently obtained in the results at different laboratories. Although the biochemical agents used are expensive this method should provide a rapid system for "finger printing" individual varieties.

DISEASE AND PEST RESISTANCE

Since new diseases cannot be introduced into Trinidad, testing is only possible against those diseases that already occur in that country - these are Black pod (caused by *Phyphthora palmivora*) and Witches' Broom (caused by *Crinipellis perniciosa*) and against the particular strains of these organisms which occur in Trinidad. Research has in the past concentrated on determining the best method for rapid testing of varieties and routine screening of the collection has now started.

COLLECTING OF GERMPLASM

The cocoa collection in Trinidad derives from Trinitario produced by natural hybridization and Forastero introductions from South America (Wood, 1991).

It is said that the first introduction in Trinidad was in 1525 - this would have been Criollo which was grown until the 18th Century when a "blast" disease decimated the plantations in 1727. In 1757 Forastero was introduced from Venezuela and this hybridized with the remaining Criollo creating the Trinitario population. Selections were made by the local planters from these populations. F.J. Pound collected 100 clones in Trinidad - the Imperial College Selections (ICS1-100).

Pound made introductions from Ecuador (1938) and the Amazon Valley (1943) of wild cocoa types - mainly for resistance to Witches' Broom which had then been introduced into Trinidad.

In the early 1940's F. Cope carried out a selection program in Grenada - the GS clones (Spence, 1991). In 1968 and 1972 Chalmers went on collecting expeditions in Ecuador, again seeking Witches Broom resistance (Warren and Kennedy, 1991). Then the joint Anglo Colombian expedition in the 1950's sampled germplasm using botanical criteria, thus providing a wider base for the genetic pool collected.

The London Cocoa Trade Amazon Project lead by J. Allen may be considered to be the most extensive systematic scientific collection. It had the defined objective of broadening the base of genetic material available to breeders and relied on collecting 25-50 plants from many populations rather than many plants from few populations. However material is still being transferred from Ecuador where it had been established after the initial collections.

Over the last five years CRU has been collecting cocoa material in the Caribbean, including Suriname and Belize and this process continues. Recently a very successful expedition was made by V. Mooledhar and W. Maharaj (both of CRU) to Belize where wild Criollo material was collected.

CONCLUSION

The greatest difficulty with the conservation of cocoa germplasm lies in the fact that the material has to be maintained as a field collection, at some considerable cost and this requires very long-term funding. Attempts to routinely tissue-culture cocoa material have met with limited success.

CRU has proposed an Endowment Fund as the only means of ensuring conservation in perpetuity. So far efforts to obtain such a fund have been unsuccessful and so the collection is maintained on the basis of project funding.

It should be noted, however, that the British Chocolate manufacturers and the Government of

Trinidad and Tobago have supported the work of the Cocoa Research Unit continuously for the last 64 years i.e. since 1930 when cocoa research was first started at the Imperial College of Tropical Agriculture (ICTA) which later (1960) became the University of the West Indies.

The present work of CRU is summarized in the Mission Statement (Appendix II) and detailed papers on the work are presented in the Annual Reports.

ACKNOWLEDGEMENTS

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Appendix I. Data recommended for a concise descriptor list for cocoa (CRU, 1994).

CHARACTERIZATION DATA

MORPHOLOGICAL
Leaf Descriptors
Flush Color
Flower Descriptors
Ligule color
Filament color
Pedicel column color
Style length
Ligule width
Sepal length

Number of ovules per ovary

Fruit Descriptors
Ridge disposition
Ridge pair separation
Pod apex form
Pod basal constriction
Husk hardness
Pod rugosity
Pod length to width ratio
Individual dried bean weight
Bean number
Bean length
Bean width

Appendix II. Mission Statement of the CRU.

1. To **conserve** on one site as a field genebank (to be known as ICG,T) all primary germ plasm existing in Trinidad.
2. To **enlarge** existing collection of primary germplasm by:-the acquisition (through exchange if appropriate) of material previously collected in the Caribbean and Latin America);
   -the conduct of expeditions to collect new material from the wild;
   -maintenance of a cacao quarantine facility in Barbados.
3. To **characterize** fully all the primary germplasm of ICG,T. This will include measure ment of:
   -heritable morphological characters (including leaf, flower pod and bean characteristics);
   -reproducible isozyme markers (using an appropriate number of enzyme systems);
   -relevant economic information (shell percentage, fat content, fat quality and flavor characteristics) of dry beans;
   -repeatable RAPD/PCR characteristics;
   -levels of tolerance to ***Phytophthora*** and ***Crinipellis*** pathogens.
4. To **catalogue** all the data collected on the primary germplasm in ICG,T and incorporate it into the International Cocoa Germplasm Database (or ICGD).
5. To **encourage** and **arrange** unrestricted international distribution through quarantine of primary germplasm from ICG,T on request. The material should be despatched with as much information as possible on the above-mentioned characters. Further, to develop and use tissue culture and/or micropropagation techniques for international distribution of germplasm under aseptic conditions.
6. To **produce** populations with enhanced levels of those genes which are of importance to plant breeders.
7. To **develop** and **adapt** appropriate scientific methodology to achieve the above-mentioned objectives.
8. To **train** scientists from cocoa-producing countries to higher degree standard by offering a variety of research projects on cocoa and to encourage the publication of the results of such work in the refereed scientific literature.
9. To **offer facilities** for visiting scientists to work on cacao subjects of relevance to the world cocoa economy. Research may be on topics not covered by the "Mission Statement", but should ideally utilize the wide range of primary germplasm at CRU and thus increase the knowledge of this material.

10. To **support** and **enhance** the cocoa research effort of Government of the Republic of Trinidad and Tobago (GORTT), in particular to identify the form of a "model cacao plant"[1] capable of significantly higher yields in an appropriate "orchard" system and furthermore to **develop** a strategy for enhancing pollination to ensure the realization of full yield potential of the model plant.
11. To **collaborate** with institutions and universities worldwide which have an interest in cocoa research.

[1] In terms of plant size, shape, habit of branching, flowering and photosynthetic potential in relation to appropriate levels of moisture, temperature and light intensity.

VARIATIONS IN FRUIT CHARACTERISTICS AMONG SELECTED GUAVA (*PSIDIUM GUAJAVA*) GENOTYPES

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ABSTRACT

Sixty-seven lines, selections and varieties of guava (*Psidium guajava*) were planted in 1971 at the Fortuna Experiment Substation, Juana Díaz in the south central region of Puerto Rico to observe their behavior and fruit quality. Fifty four were still thriving in 1991. During the 1991 and 1992 seasons, fruits were harvested for evaluation as to appearance, flavor, Brix, Ph, acidity, percentage of reducing sugars and percentage total sugars. Several varieties achieved acceptability, depending on the criterion used. However, 57-6-107, R-264, D-18, 57-6-79 and G-447 selections appear to be the highest rated as to flavor and appearance. Other varieties were found acceptable in terms of the various parameters studied. Unacceptable fruits (as to flavor) were rejected due to their high acidity.

RESUMEN

Variación de las características de las frutas entre genotipos de guayaba (*Psidium guajava*)

En 1971 se sembraron líneas, selecciones y variedades de guayaba en la región costera semiárida del Sur de Puerto Rico, Subestación Experimental Agrícola de Fortuna, Juana Díaz. De los 54 genotipos existentes en 1991 se cosecharon frutas para evaluar su calidad en términos de sabor, apariencia, Brix, ph, acidez, azúcares reductoras y azúcares totales. Las líneas 57-6-107, R-264, D-18, 57-6-79 y G-447 resultaron, en promedio, las de mejor sabor y apariencia. Las frutas mostraron gran variación en cuanto a las características evaluadas.

INTRODUCTION

Guava (*Psidium guajava*) originated in the American tropics. The Aztecs named it "Xalxocotl". It is also known as goyabe (French), guajava (German), goiaba (Portuguese) and aracá or guacú (Brazil) (15). Popenoe (15) suggests that the guava originated in Haiti. Today, it is commercially grown in South Africa (2, 3, 4, 7), Taiwan (8), the French Antilles (9), Hawaii (16), Florida (5, 11) and California, among other parts of the world.

The guava is a small tree (up to 20 feet high) with broad, spreading canopy, branching freely close to the ground. It has opposite, oblong leaves, with prominent veins below, 3 to 7 inches long. The flowers are white, about 1 inch in diameter, borne in axils of leaves of recent growth. The fruit may be round, ovoid or pear shaped. It weights from one ounce to 1 pound. The skin color is usually yellow-green and pulp ranges from white, yellow, pink to red. Flavor varies from sweet to highly acid. It as a distinctive aroma, from mild and pleasant to strongly penetrant. (5, 9, 15).

Guavas can survive and even thrive in a variety of environments, although 2° C may be too cold for new shoots to survive. A wide range of rainfall is acceptable. An excess of humidity may, however, negatively affect fruit production and quality; for that reason, in Puerto Rico it may be advisable to plant this crop in the dry South Coast, with supplementary irrigation.

Possible planting spacings are 20 x 20, 20 x 25 or even 25 x 25 feet (5, 8, 10), depending mostly on the use of pruning practices. Pruning may play an important role in bringing trees into bearing

early, as well as producing heavy crops, but intensive pruning regimes may contribute to shortened lifespans of the orchards (8). For this reason (and due to disease, too) the orchards in Taiwan last only 10 or 12 years, while the South African orchards may last 20 to 25 years, or more. (2, 3, 4 8).

In Puerto Rico, Singh Dhaliwal (6) studied glomerella (*Glomerella cingulata*), a disease not mentioned in the literature from Hawaii, Florida, Taiwan or other areas, but relatively important here. This disease causes mummification and blackening of immature fruits and rotting of mature fruits. No resistant varieties have been found, although some tolerant lines might be available.

Rodríguez and Iguina (12, 13) evaluated several cultivated guava clones in Puerto Rico and recommended some of them based on flavor, storage periods, keeping qualities and nectar yield. Malo and Campbell (11) mention nine "superior" varieties and hybrids suited for florida. Grech (8) recommend six white cultivars commercially apt for Taiwan. Bourdelles and Estanove (9) emphasized guava's high ascorbic acid content (four or five times that of oranges), along with vitamins A and B, iron, phosphorus and calcium. At the University of Hawaii, Ito and Nakasone (16), studied nine cultivars for processing and preparation of desserts, among them one brought from Puerto Rico (Puerto Rico No. 2 or Trujillo No. 2), suited to their conditions. In their 1971 study, Rodríguez and Iguina (13) selected seven clones suitable for the production of lasting nectares stored for nine month at 89° F (29.4° C). These clones were 57-9-114 (Rico 18), 58-3-71 (Rico 13), 57-4-30 (Rico 21), 57-2-142 (Rico 19), 57-2-51 (Rico 20), D-13 (Rico 4) and Trujillo 2 (Rico 2). Quality evaluation of clone 57-2-142 rated particularly high in flavor, nectar yield, and was superior to the wild fruit control.

Guavas grow wild in the dry savannas of Puerto Rico's arid South Coast. Yet at present only one grower has been able to establish a major guava plantation in the island, next to the town of San Germán. If farmers are to grow guavas commercially, it is imperative to test selected, promising varieties to determine whether they will adapt to, and will perform under, Puerto Rico's South Coast specific conditions of high temperature, dryness, soils and overall environment. Several lines have been surveyed at the Fortuna Agricultural Experiment Substation and seem to be adequate for commercial production.

The objective of this paper is to describe certain fruit characteristics featured by selected guava genotypes.

MATERIALS AND METHODS

Two hundred sixty-nine trees representing 67 lines, selections and varieties were contour-planted, 10 and 11 June 1971 on a highly alkaline, (pH 7.5 - 8.5), Aguilita gravely clay loam, 20 to 60% slope (14), at the Agricultural Experiment Station at Fortuna, Juana Díaz. Trees of the same line, selection or variety were planted next to one another. Many of the individual trees died out through the 20-year period and were not replaced. At this time, 149 trees died out through the 20-year period and were not replaced. At this time, 149 trees and 54 lines, selections and varieties are still represented in the collection.

The orchard was planted on marginal land, a situation that helps to assess the vigour and endurance of the surviving types, particularly of the 20 selections whose original representatives are all or almost all still alive and thriving: 57-4-120 (four out of five trees), G-864 (all four trees), 57-9-114 (all six trees), R-258 (all five trees), G-718 (four out of five trees), 57-7-19 (all five trees), 58-2-75 (all five trees), 57-6-107 (all five trees), D-13 (four out of five trees), R-264 (all five trees), 57-8-163 (four out of five trees), 57-1-42 (Four out of five trees), 57-4-30 (four out of five trees), 57-8-173 (all five trees), D-18 (all five trees), G-443 (four out of five trees), 57-6-79 (four out of five trees) and Q-241 (four out of five trees). This does not mean that the missing trees were particularly fragile or unadapted. Some of the single trees representing a genotype are vigorous plants. Fruits from selected varieties were harvested during 2 consecutive years and described in terms of weight, color, height, diameter and flesh thickness. Agronomic evaluations such as production per hectare seem inappropriate at this time.

This planting was intended to be a plant germplasm repository for observation of the performance of the various trees. Appearance of whole fruits, pulp color and flavor were evaluated by a taste panel in the Food Technology Laboratory.

The Lane and Eunon Volumetric Method was used to determine the percentage of reducing and total sugars. The skins were removed from seven or eight randomly selected frozen fruits, which then were left to attain room temperature. The pulp was then shaken in a waring blender for 1 to 1/ 2 minute and seeds removed by sieving (U.S. Standard #8,236 mm. or 0.0937 in. mesh). Total sugars were determined with 5 ml. of an invertase solution of 5 mg/ml/50 ml of reducing sugars solution.

RESULTS AND DISCUSSION

Because of the great variability observed, the data obtained were not statistically analyzed. In spite of that fact, information was obtained that could be of value to other researchers, as well as to Extension workers and farmers. Awareness of this limitation is important in interpreting the data here in reported.

Table 1 shows a preliminary description of some of the lines, selections and varieties represented at the Fortuna Substation.

Tables 2 and 3 present data for sensory appraisal of guava varieties. In 1991, 11 varieties were found acceptable in appearance (whole fruit and pulp color) and flavor in a + 2, - 2 scale (+ 2 = very acceptable; - 2 = not acceptable). Regarding all three attributes, highest scored were varieties D-18, 57-4-120, 57-6-107, R-264, 57-6-79 and 57-8-163. Varieties G-718, 57-7-19, 58-8-173 and 57-6-112 were found acceptable in flavor and pulp color but rejected in appearance. Varieties 58-2-75, 57-4-30, Cibuco 4, 571-128, and 57-7-138 were rated not acceptable in the three quality attributes evaluated.

In 1992, al guava fruits were judged acceptable in appearance except varieties IRPI-12238, G-443, 57-9-64 and 58-8-81. Appearance of the pulp was rated as not acceptable in varieties Q-241, 53-3-71, M-184, 5-8-173, 57-1-42, 57-6-2, 57-4-30 and R-258. All other varieties were found acceptable by the panelists. Flavor was found acceptable in guava varieties IRPI-12238, D-18, 57-6-79, 57-8-173, G-447, R-264, 57-10-137, 58-8-81, 57-6-112, G-718, 57-1-129, 57-9-64, 57-6-107, R-258 and G-19. Regarding all three attributes, acceptable varieties were D-18, 57-6-79, G-447, R-264, 57-10-137, 57-6-112, G-718, 57-1-129, 56-6-107 and G-19.

Types rated as "Unacceptable" as to flavor are not necessarily low quality fruits. Low rates mean that they are too acid and, therefore, not suitable for fresh consumption, but may be suitable for processing. Tables 4 and 5 present data of the sugar content of selected guava types. Tables 6 and 7 present acidity, °Brix and Ph of selected types.

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Table 1. Preliminary description of selected mature guava fruits.

Variety Selection or line	Average weight of 10 fruits (kg)	External color 1/ (green yellow)	Internal color 2/ (pink)	Average height of 10 fruits (cm)	Average diameter of 10 fruits (cm)	Average flesh thickness of 10 fruits (cm)	Taste 3/
57-1-57	0.045	1	1	4.72	4.21	0.53	1
57-6-79	0.086	2	1	5.31	5.28	0.86	2
Cibuco 4	0.055	2	2	2.37	4.60	0.62	3
IRPI-12238	0.055	1	1	4.66	4.42	0.63	1
Q-141	0.11	1	1	5.27	5.93	1.05	2
57-6-71	0.11	1	1	5.58	5.20	0.71	1
M-2	0.086	1	2	4.59	5.33	0.81	3
57-4-16	0.064	1	2	4.27	4.93	0.62	2
58-3-71	0.086	1	2	4.87	5.38	0.72	2
57-6-22	0.059	1	1	5.08	4.69	0.84	2
G-443	0.082	1	1	5.02	5.14	0.75	1
D-18	0.10	2	1	5.43	5.65	0.98	1
57-2-95	0.11	1	1	5.62	5.90	1.15	2
M-1-84	0.13	2	1	5.53	6.00	0.77	1
57-4-30	0.11	1	1	6.17	5.28	0.84	3
57-1-28	0.13	1	1	6.27	5.87	0.83	2
57-8-173	0.095	1	1	4.74	5.30	0.89	2
57-6-112	0.073	1	1	5.10	4.74	0.67	2
57-1-42	0.11	1	2	5.45	5.38	0.70	2
57-2-134	0.082	1	2	4.85	5.18	0.75	2
57-6-2	0.073	1	1	5.04	4.65	0.69	1
57-8-141	0.064	1	1	4.48	4.44	0.50	2
57-10-137	0.11	1	2	5.45	5.66	0.08	3

1/ 1-light green yellow; 2-deep green yellow
2/ 1-light pink; 2-deep pink.
3/ 1-sweet; 2-semi sweet; 3-tart

Table 2. Sensory evaluation of selected guava varieties, 1991.

	Mean values[1]		
	Appearance		
Variety	Whole	Pulp	Flavor
57-4-120	1.00	1.33	1.17
57-9-114	0.67	1.117	0.67
R-258	1.33	0.83	0.60
G-718	0.33*	1.17	1.20
57-7-19	0.00*	1.25	0.50
58-2-75	0.33*	-0.17*	-0.00*
57-6-107	0.50	1.17	1.40
D-13	0.80	1.25	1.25
R-264	1.20	1.25	1.25
57-8-163	1.20	1.25	0.75
D-18	1.00	1.33	1.33
57-4-30	0.29*	0.29*	0.14*
57-6-79	1.00	1.00	1.14
G-241	0.71	0.57	0.00*
57-10-137	-0.14*	0.57	0.86
57-8-173	0.33*	0.83	1.33
M-2	1.17	1.67	0.83
57-6-71	0.80	0.40*	0.00*
53-3-71	0.00*	1.00	-0.40*
57-2-95	0.83	1.33	0.00*
M-184	1.20	1.00	0.40*
57-1-57	0.75	1.25	0.25*
57-6-112	0.25*	1.00	1.25
Cibuco-4	0.00*	0.00*	-1.50*
G-447	0.67	0.83	1.17
57-1-128	-0.75*	-0.75*	-1.00*
57-7-138	0.33*	0.17*	-0.67*

[1] +2, -2 scale; +2 = very acceptable, +1 - acceptable, 0 = questionable; -1 = slightly unacceptable; -2 - not acceptable.

*Sample not acceptable.

Table 3. Sensory evaluation of selected guava varieties, 1992

Variety	Rating[1]		
	Appearance		
	Whole fruit	Pulp	Flavor
57-2-95	0.60	0.60	-0.40*
M-2	1.40	1.40	-0.40*
IRPI-12238	0.00*	0.80	0.80
G-443	0.40*	0.60	0.00*
57-6-71	1.00	1.00	0.30*
D-18	1.23	1.31	1.31
57-6-79	0.54	0.92	1.08
Cibuco-4	1.23	0.92	-0.08*
Q-241	1.46	0.38*	0.38*
53-3-71	0.62	0.23*	-0.69*
57-4-16	1.00	1.75	-0.22*
M-184	0.90	0.12*	0.11*
578-173	0.70	0.25*	0.78
57-8-163	0.90	1.50	0.33*
G-447	0.80	1.00	1.33
58-8-48	0.80	1.50	0.00*
57-1-42	1.00	0.00*	0.33*
R-264	0.50	0.50	1.17
57-8-141	1.13	1.88	-0.25*
57-10-137	1.13	1.38	0.88
57-1-28	1.75	1.00	0.13*
58-8-81	0.13*	0.50	1.75
D-13	1.25	0.50	-0.13*
57-6-2	0.80	0.20*	-0.44*
57-6-112	0.60	1.80	1.20
57-4-30	0.60	-0.60*	-0.60*
G-718	0.83	0.83	0.50
57-1-129	0.83	1.33	0.67
57-9-64	0.33*	1.67	1.00
57-6-107	1.17	1.67	1.67
57-7-19	1.00	1.17	0.33*
57-9-114	1.25	1.25	-0.25*
R-258	0.75	0.25*	0.75
G-19	1.75	2.00	1.75

[1]+2, -2 scale: +2 very acceptable; 1 = acceptable; 0 = questionable; -1 = slightly unacceptable, -2 = not acceptable.

*Samples rated not acceptable.

Table 4. Average sugar content of selected guava types, 1991.

Sample	Sugars	
	Reducing, %	Total, %
M-184	5.81	6.93
57-6-112	4.13	6.78
53-3-71	4.42	4.95
CIBUCO-4	6.08	6.33
57-1-57	4.09	5.58
C-447	12.22	13.31
57-1-28	5.04	6.20
57-4-30	6.05	6.58
57-6-79	3.59	7.52
G-241	5.03	7.19
57-8-163	3.67	6.29
57-2-95	3.65	6.39
D-13	4.56	5.79
57-9-114	4.88	7.47
M-12	6.65	7.86
57-10-137	4.16	7.61
57-6-107	5.62	7.35
57-7-19	5.00	5.56
R-264	9.71	10.93
57-8-173	6.72	9.26
D-18	9.76	9.59
57-7-138	6.37	9.08
R-258	4.31	7.95
57-6-71	8.75	9.92
57-4-120	6.17	9.53
58-2-75	5.12	8.21
G-718	3.17	7.18

Table 5. Average sugar contents of selected guava types, 1992.

Sample	Reducing %	Total, %
58-8-81	7.48	8.03
57-9-64	6.47	6.48
G-447	6.15	7.01
57-1-28	5.95	9.02
57-8-109	5.79	6.84
G-19	5.35	6.26
R-264	5.19	5.88
D-18	5.16	5.75
M-2	5.04	5.60
IRPI-12238	4.69	5.32
57-7-19	4.54	4.53
57-6-112	4.48	6.03
CIBUCO-4	4.33	5.52
G-443	4.24	4.76
57-8-173	4.20	5.66
G-718	4.20	4.83
M-184	4.20	5.31
57-6-2	3.90	3.92
R-258	3.90	7.55
53-3-71	3.85	4.17
57-9-114	3.72	5.71
58-8-48	3.67	4.98
D-13	3.66	4.13
57-4-16	3.63	4.06
57-1-42	3.53	7.22
57-4-30	3.48	3.24
57-1-129	3.40	5.96
57-8-163	3.31	5.94
57-6-71	3.29	3.25
57-10-137	3.11	5.42
57-8-141	3.10	3.73
Q-241	2.97	3.98
57-6-79	2.97	4.63
57-2-95	2.80	4.81

Table 6. Degrees brix, pH and and acidity percent of selected guava types, 1991.

Sample	°Brix	pH	Acidity
R-364	16.4	4.13	0.63
D-13	14.2	4.11	0.66
57-7-19	12.5	3.51	1.36
57-8-163	12.1	3.48	1.15
R-258	12.5	3.76	1.10
57-6-107	13.9	3.92	0.94
G-718	12.7	3.66	1.02
57-8-173	12.8	3.33	1.44
57-2-95	11.5	3.33	1.39
D-18	15.0	4.15	0.56
M-2	12.3	4.44	0.35
57-9-114	14.2	3.32	1.36
57-4-120	14.0	3.52	0.97
58-2-75	13.4	3.54	1.17
57-4-30	11.9	3.33	1.45
57-6-79	11.2	4.24	0.56
57-10-137	12.3	3.41	0.95
6-241	12.2	3.31	1.48
Cibuco-4	15.0	3.21	2.01
M-184	13.6	3.24	1.46
57-1-28	13.8	3.65	1.41
G-447	19.8	3.97	0.74
57-1-57	11.3	3.69	0.99
53-3-71	9.4	3.28	1.39
57-6-71	15.3	3.82	0.60
57-6-112	11.7	3.52	1.02
57-7-138	15.5	4.09	1.68

Table 7. Degrees brix, pH and acidity percent of selected guava types, 1992.

Sample	pH	Brix	% Acidity
G-19	4.37	11.1	0.42
57-9-114	3.38	10.5	1.39
57-6-107	4.42	10.3	0.32
58-8-81	3.94	12.4	0.51
57-8-141	3.22	7.8	1.37
57-1-129	3.80	10.2	0.83
57-10-137	3.42	8.2	0.90
57-7-19	3.83	8.7	0.95
57-9-64	3.77	10.2	1.12
57-6-2	3.76	8.3	1.14
D-13	3.41	8.5	1.72
57-1-28	3.24	9.6	1.49
R-264	4.21	9.0	0.50
57-8-173	3.55	9.2	1.13
57-1-42	3.49	11.2	1.06
R-258	3.45	11.9	1.02
G-718	3.63	8.2	0.96
Q-241	3.56	6.9	0.94
G-447	4.23	10.3	0.51
M-2	3.41	9.0	1.30
57-4-16	3.36	7.2	1.16
57-8-163	3.53	9.0	0.85
M-184	3.60	9.2	1.02
53-3-71	3.46	7.2	0.99
57-6-71	3.81	8.3	1.80
57-4-30	3.43	8.0	1.66
G-443	3.43	8.5	1.09
57-2-95	3.30	7.8	1.32
Cibuco-4	3.01	10.4	1.98
IRPI-12238	4.08	7.9	0.39
57-6-79	4.21	8.3	0.40
57-6-112	3.78	9.6	0.88
57-6-71	4.07	9.0	0.45
58-8-48	3.24	8.0	1.47
D-18	4.31	8.5	0.38

PROMISING PAPAYA VARIETIES FOR THE CARIBBEAN

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ABSTRACT

Fourteen promising papaya (Carica papaya L.) varieties were identified in a germplasm characterization study established at the Lajas Experiment Station on 7 April 1993. The large fruited (> 2 kg) processing type cultivars 'Villalba', 'Giant Panama Eet' and 'Cartagena' had higher yields than the traditional commercial cultivar 'Puerto Rico 6-65'. 'Yuen Nong No. 1', 'Tainung No. 5', 'Khag Naun' and 'Solo 40' have elongated fruits of medium size (1-2 kg), and are well suited for production of immature or mature fruit for local consumption and/or export to Latin/Asian markets. Yield of solo type 'Rafael' was not significantly different from that of the commercial 'Sunrise' cultivar, but hermaphroditic plants of 'Rafael' had 99.3% marketable fruit compared to only 78% for 'Sunrise' due to a high frequency of carpellody. Papaya cultivars identified as desirable for home gardens and/or specialty markets include 'Paco', 'Washington 5', 'Cariflora', 'Honey Gold', 'Puerto Rico 6-65 Dwarf' and chlorophyll mutant HCAR 185.

INTRODUCTION

Papaya is a high value tropical fruit with great potential for increased production in the Caribbean region. However, despite favorable climate and proximity to major markets, Caribbean papaya production in recent years has experienced little growth or has actually declined. While world papaya production increased almost ten percent from 1990 to 1992, annual production in the Caribbean has remained stagnant at about 52,000 Mg (FAO, 1993). In Puerto Rico annual papaya production has declined steadily since 1986, dropping from 4,082 Mg to a low of 907 Mg in 1992 (Troche-Ducot, 1993).

Among the most important limiting factors contributing to low papaya production in the Caribbean are diseases and the scarcity of high quality seed of superior varieties available to the grower. Papaya ringspot virus (PRV) and papaya bunchy top (PBT) are destructive, vector-transmitted systemic diseases that affect papaya plantings in the Caribbean region (Hepperly and Esnard, 1991). Both diseases decrease the economic life of the orchard, increase costs of production, and result in reduced yield and fruit quality. No effective control exists for either disease. Growers in Puerto Rico also experience difficulty in obtaining quality seed of good papaya varieties. Very little papaya breeding or varietal evaluation has been done in Puerto Rico since the release of 'Puerto Rico 6-65' in 1966 (Singh Dhaliwal et al., 1966). 'Puerto Rico 6-65' and related landraces are still the dominant papaya genotypes grown in Puerto Rico, but are primarily processing types not well suited for marketing as fresh fruit; furthermore, available seed is highly heterogeneous and contains a high proportion of undesirable male plants. 'Sunrise' is the other commonly grown cultivar in Puerto Rico; it has a high quality fresh market fruit, but produces a large number of unmarketable, misshapen fruits due to a high frequency of carpellody. 'Sunrise' also has a small fruit size which is not suitable for all markets. Both 'Puerto Rico 6-65' and 'Sunrise' are susceptible to PRV and PBT.

Thus there is a need in the Caribbean for introduction and/or breeding of new papaya varieties with desirable characteristics: high yield, disease resistance, desirable fruit type and high fruit quality. The objective of this work was to screen diverse papaya germplasm to identify promising genotypes suitable for cultivation in the Caribbean or for use in breeding new cultivars for the region.

MATERIALS AND METHODS

A collection of diverse papaya germplasm was assembled comprising 45 genotypes from Puerto Rico, Florida, Hawaii and 8 foreign countries (Table 1).

Table 1. Origin of papaya germplasm used in the study.

Country	No. accessions
Puerto Rico (USA)	6
Florida (USA)	1
Hawaii (USA)	8
China	1
Dominican Republic	1
India	1
Nigeria	10
Panama	1
South Africa	1
Taiwan	1
Thailand	3
Unknown	11

Seeds were sown February 1, 1993 in plastic bags each containing 2048 cm^3 of a 1:1:1 Pro-Mix BX:sand:field soil mix. After germination, plants were maintained under 47% shadecloth and fertilized weekly with a commercial water soluble 20-20-20 fertilizer. Plants were transplanted to the field at the Lajas Experiment Station on April 7, 1993 on plastic-mulched rows with 1.52 m intrarow spacing and 3.7 m between rows. The soil is Fraternidad clay (udic cromusterts, very fine, montmorillonitic isohypothermic), with a pH of 6.7, 35.0 mg kg^{-1} P and 0.51, 18.33 and 15.84 cmol kg^{-1} K, Ca and Mg, respectively. Mean annual rainfall is 1100 mm.

Papaya genotypes were considered treatments, and experimental units of 4 plants were replicated 3 times in a randomized complete block design. Checks were 'Puerto Rico 6-65' and 'Sunrise', and borders consisted of 'Puerto Rico 6-65'. Weeds were controlled by cultivation and spot treatment with 1% glyphosate (Roundup). Malathion sprays were applied weekly to control insect vectors in an attempt to prevent early infection by PRV and PBT; spraying was discontinued after first harvest. Drip irrigation was applied as needed, and nutrients were applied through the drip system following a recommended fertilizer schedule (Anonymous, 1987). Urea (46% N) was used as a source of N, phosphoric acid (H_3PO_4) provided P and potassium nitrate (KNO_3) was used to supply N and K.

Data were recorded for traits of horticultural interest; total fruit yield, mean fruit weight, tree size and virus resistance score are reported in this paper. Plants were visually evaluated for virus symptoms using a 1 (highly resistant) to 9 (highly susceptible) scale where 1 = no symptoms; 3 = leaves normal size and shape, little distortion or mottling, fruit set normal; 5 = leaf size reduced, moderate distortion and/or mottling, fruit set reduced; 7 = leaf size reduced 50%, distortion and/or mottling, little or no fruit set; and 9 = leaf size severely reduced, severe distortion and/or mottling, no fruit set, eventual death. A virus score of less than 5 is considered a useful level of resistance. All plants had symptoms of virus infection at the time of evaluation. Analyses of variance (ANOVA) were calculated for quantitative variables, and means were separated using least significant differences (LSD).

RESULTS AND DISCUSSION

Of the 45 papaya genotypes compared in this field trial, 14 were selected for further evaluation based on superior performance, and are described in this paper. These genotypes may be grouped into processing, fresh market and specialty market/home garden classes depending on their principal use. Varieties grown primarily for processing purposes should have a high yield of large, thick-fleshed fruit; fruit quality is not of primary importance since sugar and other flavorings are added during processing. Fresh market papaya cultivars include small-fruited solo types, grown primarily for export as mature fruit to temperate zone markets, and cultivars with larger, elongate fruit suitable for local consumption or export to Latin/Asian markets either immature (green) or mature (ripe). Fresh market types should be high-yielding, and must have desirable size and shape, as well as high fruit quality, since they are consumed directly. High fruit quality is also important in papaya cultivars for specialty market and home gardens. Although disease resistance is desirable in all three classes, it is an especially important trait in specialty market types, where fruit may be produced organically, or in home garden situations, where chemical pest control is likely to be limited.

Processing Types

'Villalba', 'Giant Panama Eet' and 'Cartagena' had higher yields and larger mean fruit weight than the control, 'Puerto Rico 6-65' (Table 2). Of these, 'Villalba' was an outstanding producer, with a total yield of 104 Mg ha^{-1}. Trees of these three cultivars are large (>2.4 m), which is a disadvantage for harvesting; however, their superior yield and large fruit size make them ideal for production of papaya for processing. 'Cartagena' had a virus score of 4.6, which is a moderate but useful level of resistance. The other cultivars had low resistance to virus infection.

Table 2. Origin, mean fruit yield, fruit weight, tree size and virus score of processing type papaya cultivars grown at Lajas, Puerto Rico.

Genotype	Origin	Fruit yield	Fruit weight	Tree size†	Virus score‡
		Mg ha^{-1}	kg		
'Villalba'	Puerto Rico	104	2.3	L	6.2
'Giant Panama Eet'	Panama	86	2.6	L	6.0
'Cartagena'	Dom. Rep.	81	2.3	L	4.6
'Puerto Rico 6-65'	Puerto Rico	77	1.6	M	7.3
LSD (0.05)		26	0.3		1.3

† S = small (<1.8 m), M = medium (1.8 - 2.4 m), L = large (>2.4 m).
‡ Plants were visually evaluated for virus symptoms using a scale of 1 (highly resistant) to 9 (highly susceptible).

Fresh Market Types

'Sunrise' and 'Rafael' were identified as superior solo type fresh market papaya cultivars (Table 3). There was no significant difference between the two cultivars in fruit yield, fruit weight, tree size or virus score. Both have pyriform fruit typical of solo type papayas. The principal differentiating characteristic is percentage of carpellody in fruits of hermaphroditic trees. 'Sunrise' had a

frequency of 22% carpellody, resulting in unmarketable misshapen fruits, while 'Rafael' produced only 0.7% carpellodic fruits. Therefore, 'Rafael' may be a desirable alternative to 'Sunrise' where high frequency of carpellody is a problem.

Yields of fresh market elongate type papaya cultivars 'Yuen Nong No. 1', 'Tainung No. 5' and 'Khag Naun' were not significantly different from that of the control 'Puerto Rico 6-65' (Table 4). 'Solo 40' had a lower yield, but was selected for further evaluation fue to its high fruit quality and uniformity. All of the cultivars have a desirable fruit weight of approximately 1-2 kg, a narrowly ovoid to lanceoloid shaped fruit, and have short to medium trees, which facilitates harvest. All are susceptible to virus; 'Solo 40' is extremely susceptible, which probably contributed to its low yield.

Table 3. Origin, percent carpellody, mean total and marketable fruit yields, fruit weight, tree size and virus score of fresh market solo type papaya cultivars grown at Lajas, Puerto Rico.

Genotype	Origin	Percent carpellody	Fruit yield		Fruit weight	Tree size	Virus score‡
			Total	Marketable			
			Mg ha^{-1}		g		
'Sunrise'	Hawaii	22.0	51	44	351	L	8.3
'Rafael'	Puerto Rico	0.7	46	45	289	L	7.8
LSD (0.05)			26		300		1.3

† S = small (<1.8 m), M = medium (1.8 - 2.4 m), L = large (>2.4 m).
‡ Plants were visually evaluated for virus symptoms using a scale of 1 (highly resistant) to 9 (highly susceptible).

Table 4. Origin, mean fruit yield, fruit weight, tree size and virus scoreof fresh market elongate type papaya cultivars grown at Lajas, Puerto Rico.

Genotype	Origin	Fruit yield	Fruit weight	Tree size†	Virus score‡
		Mg ha^{-1}	kg		
'Puerto Rico 6-65'	Puerto Rico	77	1.6	M	7.3
'Yuen Nong No. 1'	China	72	1.9	M	6.8
'Tainung No. 5'	Taiwan	68	1.0	S	7.4
'Khag Naun'	Thailand	66	1.6	S	6.9
'Solo 40'	Hawaii	49	0.9	M	8.3
LSD (0.05)		26	0.3		1.3

† S = small (<1.8 m), M = medium (1.8 - 2.4 m), L = large (>2.4 m).
‡ Plants were visually evaluated for virus symptoms using a scale of 1 (highly resistant) to 9 (highly susceptible).

Specialty Market/Home Garden Types

'Paco', 'Washington 5' and 'Cariflora' are excellent cultivars for specialty markets and home

gardens. They produce high yields of high quality fruit on medium sized trees (Table 5). In addition to these desirable characteristics, 'Washington 5' and 'Cariflora' have good levels of virus resistance. The primary disadvantage of these cultivars in terms of commercial production is fruit shape; 'Paco has ovoid to spheroid fruits, and 'Washington 5' and 'Cariflora' have a spheroid fruit shape. Perhaps existing consumer preference for pyriform or elongate fruit could be modified with the introduction of these outstanding cultivars.

Table 5. Origin, mean fruit yield, fruit weight, tree size and virus score of specialty market home garden type papaya cultivars grown at Lajas, Puerto Rico.

Genotype	Origin	Fruit yield	Fruit weight	Tree size†	Virus score‡
		Mg ha^{-1}	kg		
'Paco'	Puerto Rico	75	1.1	M	5.6
'Washington 5'	India	72	0.8	M	3.7
'Cariflora'	Florida	65	0.6	M	3.8
'Honey Gold'	South Africa	49	0.9	L	5.4
'Puerto Rico 6-65 Dwarf'	Puerto Rico	46	0.4	S	8.6
HCAR 185	Hawaii	29	0.3	M	8.1
LSD (0.05)		26	0.3		1.3

† S = small (<1.8 m), M = medium (1.8 - 2.4 m), L = large (>2.4 m).
‡ Plants were visually evaluated for virus symptoms using a scale of 1 (highly resistant) to 9 (highly susceptible).

'Honey Gold', 'Puerto Rico 6-65 Dwarf' and chlorophyll mutant HCAR 185 are desirable a curiosities for the home garden. 'Honey Gold' bears a sweet fruit that is best eaten soon after harvest, as it ripens quickly and is very soft at maturity. 'Puerto Rico 6-65 Dwarf' is an extremely small plant (mean 135 cm height) well suited to small gardens or for use as edible landscaping. The immature fruit of chlorophyll mutant HCAR 185 have a golden yellow color; the abundance of these small fruits on a medium size tree has a very ornamental aspect. The fruit is edible and of fair quality.

CONCLUSIONS

In a field evaluation of 45 diverse papaya genotypes at Lajas, Puerto Rico, 14 cultivars were identified as having potential for cultivation in the Caribbean or for use in breeding new varieties adapted to local conditions. It is hoped that the introduction of new, superior cultivars will help to stimulate an increase in papaya production in the region.

ACKNOWLEDGEMENTS

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PRIMING PAPAYA SEEDS REDUCES SEED GERMINATION TIME

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ABSTRACT

Papaya seeds from four open pollinated papayas varieties 'Cariflora', 'Puerto Rico 6-65', 'Solo-64' and 'Waimanalo 162' were soaked for 5 days in water or -1 MPa solutions of $CaCl_2$, $Ca(NO_3)_2$, KCl or KNO_3. Following priming, treated seeds were rinsed and air dried for two days prior to planting. Untreated seeds were planted as controls. Seedling emergence was recorded daily. Priming reduced the mean time for seedling emergence for all salt treatments. The KNO_3 treatment resulted in the greatest seedling emergence in the shortest length of time. Pretreating papaya seeds with a salt solution can be used to enhance seed germination and plant emergence in a shorter length of time than untreated seed.

INTRODUCTION

Papaya seeds have been attributed with poor germination in the propagation of papaya (Chacko and Singh, 1966; Perez et al., 1980). Poor germination has been associated with growth inhibitors present in the sarcotesta, the gelatinous membrane surrounding the seed, as well as the seed coat itself (Lange, 1961; Reyes, et al., 1980). Seed priming is a system of soaking seeds in a solution for a given period of time prior to planting. Seed priming is commercially used to reduce germination time and increase the uniformity of the seedling stand (Samfield, et al., 1990; Wartidiningsih, et al., 1994). Uniform plant emergence allows for the full growth potential of every seedling. When seedlings emerge unevenly over a period of time, the first to emerge shade the latter emerging seedlings and develop ahead of the latter emerging seedlings.

Seed germination is divided into three phases: imbibition, lag phase and radicle emergence (Kozlowski, 1972). Imbibition is the physical uptake of water by a seed. Imbibition is not an indication of seed viability because even dead seeds will draw up water and swell. The lag phase is the time during which the cell membranes are repaired and the metabolic processes in the cell are reinitiated. Radicle emergence occurs when the root protrudes from the seed due to cell elongation and cell division. The purpose of seed priming is to allow the first two phases of seed germination, imbibition of water and restoration of cellular biochemical activity, but to inhibit the final phase, radicle emergence. Once the radicle has emerged, seeds are considered germinated and dehydration is lethal. Either salt solutions or water can be used for priming. When using water to prime seeds, priming should be terminated before radicle emergence. The osmotic potential is the key factor in developing salt solutions for seed priming. An osmotic potential of -1 MPa will allow proper seed priming and yet inhibit radicle emergence (Smith and Cobb, 1991). The objective of this study was to use K or Ca salt solutions to develop a system for reducing the time required for papaya seed germination and seedling emergence. Seedling emergence was determined when both the hypocotyl and the seed cotyledons broke through the potting mix surface.

MATERIALS AND METHODS

Seeds were collected from mature fruits of four open-pollinated papaya varieties, 'Cariflora', 'Puerto Rico Red', 'Solo 64' and 'Waimanalo 162'. Seeds were washed to remove the gelatinous sarcotesta and any floating seeds were discarded. Floating seeds often contain aborted embryos or under developed embryos that are nonviable. Cleaned seeds were air-dried and stored in a refrigerator

at 5 °C until used. The priming solution treatments were developed to be -1 MPa as determined by a Decagon psychrometer. The salts chosen for priming solutions were: $CaCl_2$ (173 mM), $Ca(NO_3)_2$ (173 mM), KCl (232 mM) or KNO_3 (232 mM). Twenty-five seeds were placed in each half of 100 x 15 mm divided petri dishes to which 8 ml of priming solution was added. Each treatment was replicated four times. Seeds were primed for five days at room temperature (20 °C) with a change of fresh solution after 48 hr. After five days of priming, seeds were rinsed with distilled water and air dried 2 days prior to planting under greenhouse conditions in mid April at a 1 cm depth in 1:1 (v/v) Pro Mix : sand potting mix. Emergence was recorded when the hypocotyls forced the seed cotyledons above the potting mix surface.

RESULTS AND DISCUSSION

During imbibition the cell membranes have not yet been repaired from the damage incurred during dehydration of the mature ripening seed. The cells are therefor leaky and cell contents which dissolve with the uptake of water can be lost from the cell until the membrane is repaired. The loss of cell contents or electrolytes can be measured by conductivity. Conductivity readings provide an indication of the seeds passing from imbibition to the lag phase. The conductivity from all the priming solutions were the highest after the first two days and decreased by the fifth day of priming (data not presented). This indicated that the seeds were viable and able to repair the cell membranes upon imbibition of water. Dead seeds are unable to repair damaged membranes caused by dehydration and would have continuous electrolyte leakage over time. The conductivity readings indicate that the priming solutions did allow imbibition and activation of cellular membrane repair.

The effect of priming solution on total plant emergence over time was similar for all salt solution and significantly different from the control over time. The salt solutions used for seed priming provided better emergence over time than the water treatment or the control. While plant emergence began on the seventh day for all priming treatments, the start of plant emergence was delayed until the tenth day for the controls (Fig. 1). All priming treatments significantly reduced the average emergence time over the controls for all four varieties. Priming solutions containing either KNO_3 or $Ca(NO_3)_2$ had the greatest overall effect of reducing the average emergence time (Fig. 2).

The varieties selected did provide a range of response for plant emergence. Seedling emergence began on the seventh day and leveled off for 'Cariflora', 'Solo 64' and 'Waimanalo' by the twelfth day. Total plant emergence on the fifteenth day among these varieties ranged between 85% and 95% and was not significantly different. Total 'PR Red' emergence was lower at 70% but stabilized by day 15. The greatest total daily emergence for 'Cariflora', 'S-64' and 'Waimanalo' was on day 8, while 'PR Red' was similar for both day 10. The greatest average daily emergence for 'Cariflora', 'Solo 64', 'Waimanalo' and 'PR Red' was 31.4, 29.2, 26.4 and 17 respectively. These data presented are averages of the priming solution treatments without the control. Seed priming with one of the four salt solutions increased the total plant emergence for 'Cariflora', 'Waimanalo' and 'PR Red' than was possible with priming in water or no priming at all. The priming solutions had no effect on the total germination of 'Solo 64' (Fig. 3).

CONCLUSIONS

Seed priming was shown in this study to enhance the total seed germination and seedling stand establishment for slow germinating varieties or varieties with reduced viability. The benefit of seed priming was to reduce the average seedling emergence time and increase the uniformity of plant emergence. Priming papaya seeds in water or one of the four salt solutions examined benefited seedling stand establishment. One of the beneficial effects of seed priming may be to leach some of the plant growth inhibitors from the seed coat and internal seed tissues. Using a salt solution for seed priming of some papaya varieties can enhance the performance of seedling stand establishment over that obtained by water priming or unprimed seed. The uptake of the nutrient salt during

priming may increase metabolic activity during the priming process which can stimulate low vigor seeds to germinate. Pretreating papaya seeds with a salt solution can be used to enhance seed germination and provide uniform plant emergence in a shorter length of time than untreated seed. Priming papaya seeds in a KNO_3 solution resulted in the greatest seedling emergence in the shortest length of time. Seed priming can be effectively used to promote better papaya seedling stand establishment.

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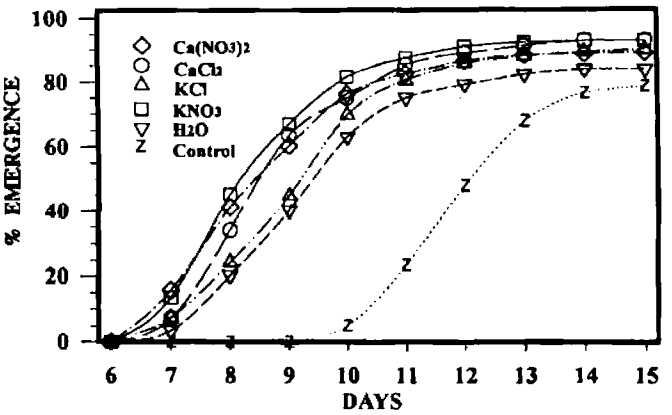

Fig. 1. Papaya plant emergence over time, combining 'Cariflora', 'S-64' and 'Waimanalo', as influenced by the salt solutions used in seed priming.

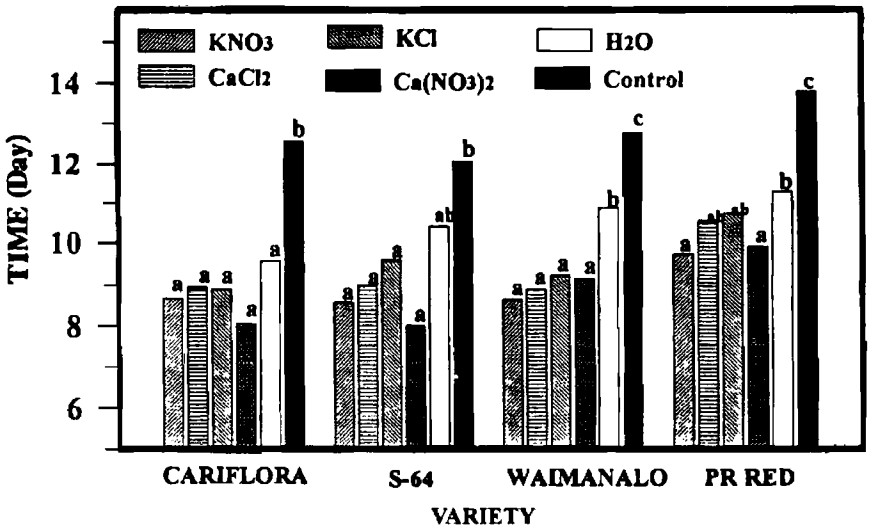

Fig. 2. Average plant emergence as influenced by papaya variety and seed priming treatment. Different letters indicate significant differences between treatments within a variety. Mean separation test based on LSD P = 0.05.

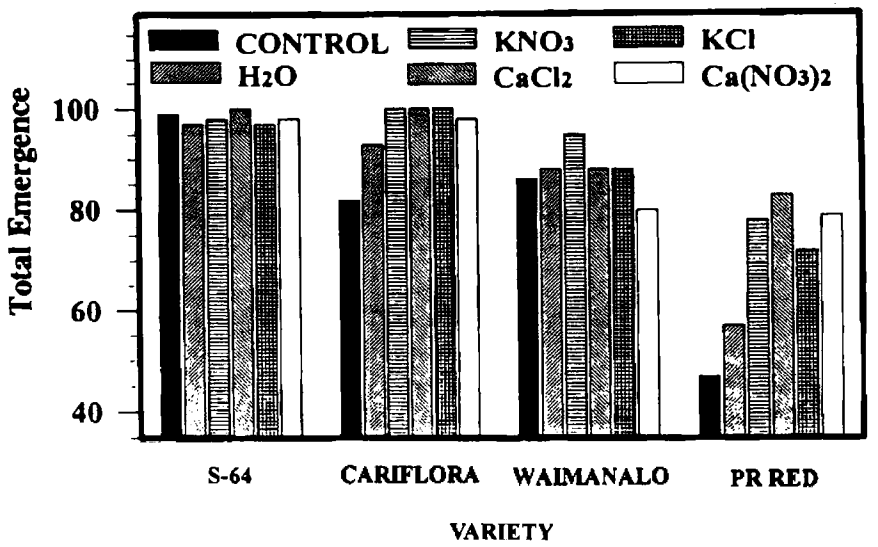

Fig. 3. Total papaya plant emergence by variety fifteen days after planting as influenced by seed priming treatment.

AN INVESTIGATION INTO THE RELATIONSHIP BETWEEN MATURITY AND SHELF LIFE OF PLANTAIN GROWN IN THE SOUTHEAST OF DOMINICA

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ABSTRACT

Ship ripening is a recurrent problem for plantain exported to England, from Dominica. In this study, bunches were harvested at different ages, ranging from 6½ to 13½ weeks after shooting. The maturity grade of each hand was scored visually (from thin to ¾ full). The caliper grade of the central finger in each hand was also recorded. Fruit were stored at 10°C, for 10 days, followed by storage at 21°C. All fruit were inspected every other day, for signs of ripening. Hands that were proximal on the bunch (first hand to set) demonstrated a significantly shorter shelf life than hands from the middle or distal end of the bunch. There was an increase in shelf life for a decrease in the age at which bunches were harvested ($P < 0.001$). This relationship was also found to be linear ($P < 0.001$). Shelf life decreased linearly, as caliper grade and maturity score increased ($P < 0.001$). The r values were highest for the bunch age/shelf life relationship (0.8311 for bunch age, compared to 0.64944 for caliper grade and 0.6575 for maturity grade), indicating that this was the most reliable indicator of shelf life. These results indicate that farmers should harvest bunches at 10 weeks (predicted shelf life 26 days, with a 95 % confidence interval of 6.3 days) after shooting, when shipping plantain to the U.K. by sea.

INTRODUCTION

Plantain has been identified as a priority crop in the diversification efforts of the Windward islands, particularly in Dominica. Plantains are grown in a wide variety of farming systems but generally production is small scale, with most farmers growing plantains on plots of 0.5 acres or less. Plantains are often intercropped with crops such as dasheen and pumpkin.

Most farmers in Dominica grow a type of plantain known as the French or Apem plantain. Its cooking and eating qualities are generally favored by East Caribbean people, both regionally and extra regionally. A number of different varieties of plantain are grown in Dominica but the most common is the "ordinary."

Traditionally, exports of plantains out of Dominica have been to other islands in the Caribbean. However, over recent years volumes shipped extra regionally, in particular to England, have increased, to approximately 220 tons per annum.

Apem plantains that are shipped extra regionally must arrive green if they are to fetch their optimum selling price. This is because many consumers consume them green, by boiling. It also allows retailers to stock the plantain over a much longer period of time before deterioration. Accounts of sales received in 1993 have shown that the average selling price of a carton of green plantain is approximately three times that of ripe plantain.

The plantain, being a climacteric fruit, continues its ripening processes when it has been harvested. At present, all plantain exported by Dominica to the U.K. are sea freighted. They are held in lockers or containers, which are refrigerated to 13°C. The journey from Roseau port to the U.K. market takes, on average, 13 days. Despite the refrigerated conditions, a significant proportion of plantains reach the market ripe. At present an average 16% of plantains exported from Dominica, to the U.K. arrive ripe. This represents a $US 570 loss in revenue for the exporter, for an "average" sized consignment (5.2 tons).

The problem of premature ripening has been confounded by a lack of understanding of the factors that affect the shelf life of the plantain. Results of research conducted on the economically dominant banana crop have often been transferred to the plantain. However, as the work of Karikari et al.(1979) showed, the physiology of their ripening processes differ greatly. This indicates a need for specific research into factors that influence the storage life of the plantain.

At present plantains bound for the extra regional market are harvested early in the morning, the day before shipment. All fruit are field packed into cartons, to improve quality. Farmers harvest fruit at the Light ¾ stage of maturity. This is assessed subjectively by the presence of ridges running lengthwise along the fingers.

In the Windward Islands, a caliper is an important tool in determining the harvest maturity of bananas. If fingers are too fat they are rejected as over grade fruit. Conversely, if they are too thin they are rejected as under grade fruit.

Various researchers (e.g. Montaya et al., 1984) have found a direct relationship between the age of a bunch of bananas and its shelf life. Work of this kind has led to the adoption, in Latin America, of a system of harvesting by bunch age. This involves tagging a bunch of bananas at fruit set and harvesting it after a fixed period of time. A similar system of tagging, in conjunction with a caliper system, has recently been introduced to the Windward Islands (WINBAN, 1993).

From the results of research carried out in Honduras, Medlicott (1992) concluded that fruit age also controls the length of green life of Horse plantains. However, it was also observed that ripening rates of fruit harvested at the same age, but at different times of year, were different. Caliper grade was found to be a less reliable indicator of shelf life, though was strongly correlated to bunch age. It was recommended that, in commercial operations, a combination of both systems be used. That is, fruit should be harvested after a set period of time (9 10 weeks) but, if their caliper grade exceeds 27, they should not be shipped by sea.

Karikari et al.(1979) also observed that an increase in bunch age led to a decline in the pre climacteric period (PCP) of Apem plantain.

Medlicott (1992) also demonstrated that the ripening rate of hands of plantain, positioned basally on the bunch (that is, the first hands to be set on the bunch), was significantly faster than that of apical hands. Similarly, Karikari et al.(1979) found that the PCP of hands of Apem plantain, harvested from the same bunch, decreased, proceeding towards the basal end of the bunch.

From field observations made in Dominica, it is claimed that for the ordinary variety ripening processes occur evenly, whilst for the larger bunched centlivre variety ripening proceeds unevenly along the bunch (Stephenson, 1986).

MATERIALS AND METHODS

No plot large enough to supply all the plantains for this trial was available. Plantains were obtained from seven plots in the Delices area.

Each plot was visited weekly, for eight successive weeks, from August 19 until October 7, 1993. On every plot, bunches that had just set the last hand were tagged and dated (approximately 1 week after shooting). Two plots (A and B) were larger and afforded more bunches at the correct stage of development for tagging. The remaining plots were smaller and generally provided only a single bunch for tagging each week. Eight bunches, in total, were tagged each week. On November 22, 1993, all 64 bunches were harvested. This provided bunches of 6½ through to 13 ½ weeks in age (eight ages in all).

As the bunch was dehanded each hand was laid out to drain in the order in which it had arisen on the bunch. Every hand was labelled with: the name of the farmer; its age (from 6½ to 13½ weeks); the bunch on which it had occurred and the position in which it had arisen on the bunch (for example, whether it was the first hand to set or the last).

The fruit were packed into cartons without clustering. The cartons were transported to the Produce Chemist's Laboratory, in the Botanical Gardens, on the day of harvest. In the laboratory the diameter

of the central finger of each hand (on the outer whorl of fingers) was measured, to the nearest tenth of a millimeter. This measurement was taken at the central portion of each finger.

The maturity of each hand was also recorded, using the subjective assessments commonly used in the field. Maturity was scored as follows: 1='Thin'; 2='Light'; 3='Light ¾; 4= '¾; 5='Full ¾.

The plantains were packed, completely at random, into cartons. No refrigerated container was available for storage at this time. The cartons were stored in a cool room, for 10 days, in an attempt to simulate shipping conditions. It was unfortunate that the temperature regulation of this room was not constant and a regime of 11°C (+2°C) prevailed during this period.

After 10 days in cool storage, the fruit were removed to the laboratory, where they were stored in an air conditioned room for the remainder of the trial. A temperature of 21°C (+1°C) prevailed.

All fruit were inspected, every two days, for signs of ripening. Since many fruit were very pale at harvest, a characteristic of many fruit harvested in this locality, it was difficult to make the distinction between fruit that were naturally pale and fruit that were beginning to ripen. Thus, shelf life was recorded as days to complete yellowing of at least one finger in the hand, since yellowing cannot be confused with inherent paleness.

Once at least one finger in the hand had completely ripened, the hand was removed from the carton.

RESULTS AND DISCUSSION

Farmer

Table 1 shows the mean shelf life of bunches harvested at different ages from the different plots.Insufficient replication was carried out to enable a full statistical comparison of shelf life between all plots, except between plots A and B. This analysis showed that there was no statistically significant difference in shelf life, between fruit of the same age, for these two farmers ($P > 0.05$).

By observation, the shelf life of fruit submitted by other farmers was generally similar to that of farmers A and B. Larger differences that may be observed are not consistent over the weeks and so no conclusion can be drawn from them. The data from the different plots has been combined in the remaining analyses.

Hand position

A statistical comparison of shelf life, between hands that had arisen from different positions on the bunch, was carried out. The shelf life of hands that were basal on the bunch, at the centre of the bunch and were the last on the bunch were compared (Table 2). For bunches that held an even number of hands, the mean shelf life between the two middle hands was calculated and used in the analysis.

This was conducted as a two way analysis of variance, with bunch age as the other variable factor.

The analysis showed that hand position had a significant effect on the shelf life of the fruit ($P < 0.01$). A statistical comparison of hand position means demonstrated that basal hands (the first hands to set) showed a significantly shorter shelf life than the middle hands ($P < 0.05$) and last hands ($P < 0.01$) in the bunch. The differences in mean shelf life between the middle hand and the last hand were not significant ($P > 0.05$).

However, differences in shelf life were not significant between hand positions, for all of the bunch ages. For example, for bunch ages of 13½, 8½, 7½ and 6½ weeks, there were no significant differences in shelf life between hands taken from different positions on the bunch. However, for bunch ages of 12½, 11½, 10½ and 9½ weeks, the last hands in the bunch had significantly longer shelf lives than the basal hands ($P < 0.05$ for weeks 12½, 11½ and 10½; $P < 0.01$ for week 9½). The last hands did not show significantly longer shelf lives than the middle hands ($P > 0.05$), except for a bunch age

of 12½ weeks ($P < 0.05$).

These results largely correspond to those of other investigators. The last hand that is set in a bunch does tend to demonstrate a longer shelf life than hands taken from basal positions on the bunch. The fact that this pattern was not observed for the oldest bunch age could be because all hands on the bunch were near to their natural time of ripening. Essentially they had all reached the stage of initiation of ripening, at the time of harvest.

The pattern of an increase in shelf life for the last hand did not persist for the youngest three bunch ages (8½ to 6½ weeks). This could be expected since, when they were harvested, these fruit were immature and well away from the time for the initiation of natural ripening. Thus, it would follow that their ripening processes would be less synchronized.

Since hand position affected the shelf life of fruit, some way of accounting for, or controlling this variation, was necessary in the remaining analyses.

Bunch age

The results (Table 2) showed a clear trend of an increase in shelf life for a decrease in the age at which bunches were harvested. This trend slowed down for the younger ages, however. This can also probably be explained by the immaturity of these fruit and consequent lack of coordination in their ripening processes. These results were highly significant ($P < 0.001$), indicating that bunch age did affect shelf life.

Linear regression analyses were carried out to explore the relationship between bunch age and shelf life. The analyses were performed separately for the different hand positions (basal; middle and last hand). An additional analysis was carried out on data obtained by combining all three positions, to give a single line.

A highly significant linear relationship was found to exist between bunch age and shelf life ($P < 0.001$), for all three separate hand positions and for the combined data ($P < 0.001$). The three regression lines were statistically compared with this single regression line. This showed that the use of three separate lines gave a significantly better fit ($P < 0.01$). The data support that relationships between bunch age and shelf life are different, for hands taken from different positions on the bunch.

These three regression lines are shown in Figure 1. The r values for basal, middle and last hands were 0.856; 0.9226 and 0.7355 respectively (the r value for the single regression line was 0.8311). This indicates that the prediction of shelf life by bunch age is most accurate for hands taken from the middle of the bunch.

Figure 1 indicates that, in order to obtain plantains with a shelf life of at least 21 days, the crop should be cut at 11½ weeks. The 95% confidence interval (C.I.) for a bunch cut at this age is 21 days +6.4 days, indicating that there is a considerable chance that the bunch would ripen in only 14 days. This wide confidence interval may be indicative of the small scale of this trial.

The 95% C.I. of a crop cut at 10½ weeks is 26 days +6.3 days. Based on the data of this experiment, one could be 95 % certain that a bunch cut at 10 weeks or less would last at least 19 days, which is closer to the shelf life that is required for a typical shipment.

In practice, it is hard to advise farmers to harvest their crop at a single age, since they harvest only once a week. Thus, a time frame of 9 to 11 weeks could be offered (9 weeks implies a shelf life of 30 days and 11 a shelf life of 23 days).

The visual appearance of fruit cut at 9 and 10 weeks was observed to be Light/Light¾ and for those cut at 11 weeks, Light¾.

Caliper Grade

Mean caliper grades for the middle hand in each bunch were calculated. These results were categorized as follows: less than 31 mm; 31 36 mm; above 36 mm.

The mean shelf life of the bunches of each category are shown in Table 3.

The differences in shelf life were highly significant ($P < 0.001$), indicating that caliper grade could act as a useful indicator of maturity. That is, with an increase in caliper grade, there is an apparent decrease in storage life.

Fruit with a caliper grade greater than 36 mm demonstrated a significantly shorter shelf life than those of 36 mm or less ($P < 0.001$). Fruit with a caliper grade of 31 36 mm showed a significantly shorter shelf life than those less than 31 mm ($P < 0.001$).

A regression analysis revealed a highly significant linear relationship between caliper grade and shelf life ($P < 0.001$), for all three hand positions and for all data combined. The use of three separate lines did not, however, give a statistically better fit than a single line, combining all data ($P > 0.05$). That is, the relationships between caliper grade and shelf life are not statistically different between hands arising from different positions on the bunch.

The single regression line is shown in Figure 2 and clearly shows that a linear model should not be fitted for this data. This is supported by the low r value for this relationship, of 0.6494.

In many banana farming systems, fruit are harvested by age but a maximum caliper grade in also used to "double check" maturity. It would not be appropriate to allocate a maximum caliper grade for Apem plantain shipped to extra regional markets, until more research is carried out.

Visual Assessment

An analysis of variance was carried out to compare the shelf life of hands taken from the middle of the bunch which had different visual maturity scores (14). The mean shelf lives for hands with each score are shown in Table 4.

The analysis of variance showed that visual maturity scores do significantly correlate with shelf life ($P < 0.001$). That is, there is a trend of a decrease in shelf-life, for an increase in maturity score. From this, it can be concluded that the visual assessments currently used to judge maturity do provide some indication of shelf life.

Regression lines were plotted and were found to be highly significant for separate hand positions and for all data combined ($P < 0.001$). The use of separate lines did not, however, give a statistically better fit than a single line, combining all data ($P > 0.05$). The single regression line is shown in Figure 3 and shows that a linear model should not be fitted for these data. The low r value for this relationship, of 0.6575, also indicates that bunch age acts as a more reliable indicator of shelf life.

Table 5 shows, for the middle hand position, the percentage of hands, with each maturity score (1 4), that lasted at least 21 days (the minimum green life required, when shipping plantains to the U.K.).These results exemplify the problem of ship ripening as it currently exists. That is, plantains which are cut by eye, at the Light¾ stage of maturity, frequently do not have the shelf life required to reach extra regional markets.

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Table 1. Mean shelf life of bunches harvested from different plots, at different ages.

	Mean shelf life (days)							
	Bunch age (weeks)							
PLOT	13½	12½	11½	10½	9½	8½	7½	6½
A	15.8	18.9	21.5	25.4	25.8	31.0	29.5	35.7
B	15.2	16.5	20.4	25.0	27.4	33.5	34.8	37.4
C	-	-	-	29.6	33.0	33.0	-	36.4
D	15.6	16.6	17.8	25.8	29.2	36.0	28.8	34.5
E	15.0	15.0	16.4	31.0	31.3	29.0	30.6	28.1
F	15.0	15.2	23.5	24.2	31.3	31.7	33.0	33.3

* indicates no bunches of this age available

Table 2. Mean shelf life for hands taken from different positions, harvested at different ages.

	Mean shelf life (days)								
	Bunch age in weeks								
Hand position	13½	12½	11½	10½	9½	8½	7½	6½	Mean
Basal	15.0	15.6	17.3	23.8	23.5	31.8	33.0	35.1	**24.4**
Middle	15.0	16.0	20.8	26.0	28.5	34.0	31.5	37.3	**26.1**
Last	16.6	20.4	22.0	28.6	29.5	33.8	30.8	34.3	**27.0**
Mean	**15.5**	**17.3**	**20.0**	**26.1**	**27.2**	**33.2**	**31.8**	**35.5**	

S.E.D. between any two values = 2.169
S.E.D. between two hand position means = 0.767
S.E.D. between two bunch age means = 1.252, with 168 d.f.

Table 3. Mean shelf life of middle hands of different caliper grades.

CALIPER GRADE	MEAN SHELF LIFE
< 31 mm a (13)	34.7
31 36 mm b (32)	28.2
> 36 mm c (19)	16.8

S.E.D for comparison of a and b = 1.626
S.E.D for comparison of b and c = 1.432
S.E.D for comparison of a and c = 1.780, with 61 d.f.
Figures in brackets represent number of bunches

Table 4. Mean shelf life of middle hands harvested at different maturity scores.

Maturity score	Shelf life(days)
1 (9)	35.1
2 (14)	31.9
3 (26)	24.8
4 (15)	17.7

S.E.D. for comparison of 1 and 2 = 2.420
S.E.D for comparison of 1 and 3 = 2.191
S.E.D. for comparison of 1 and 4 = 2.388
S.E.D. for comparison of 2 and 3 = 1.877
S.E.D. for comparison of 2 and 4 = 2.105
S.E.D. for comparison of 3 and 4 = 1.837, with 60 d.f.
Figures in brackets represent number of bunches

Table 5. Percentage of middle hands with actual shelf life of 21 days.

VISUAL MATURITY SCORE	PERCENTAGE
1	100
2	100
3	69
4	13

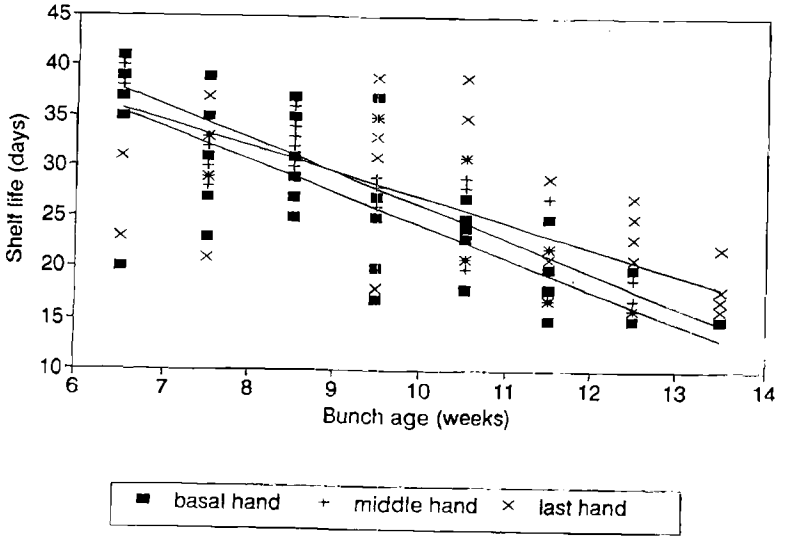

Fig. 1. Bunch age/shelf life relationship

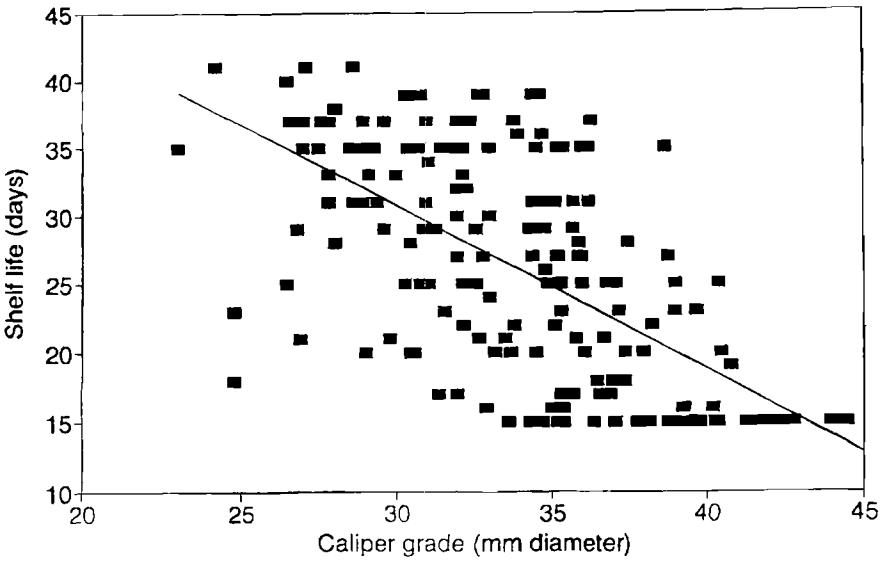

Fig. 2. Caliper grade/shelf life relationship

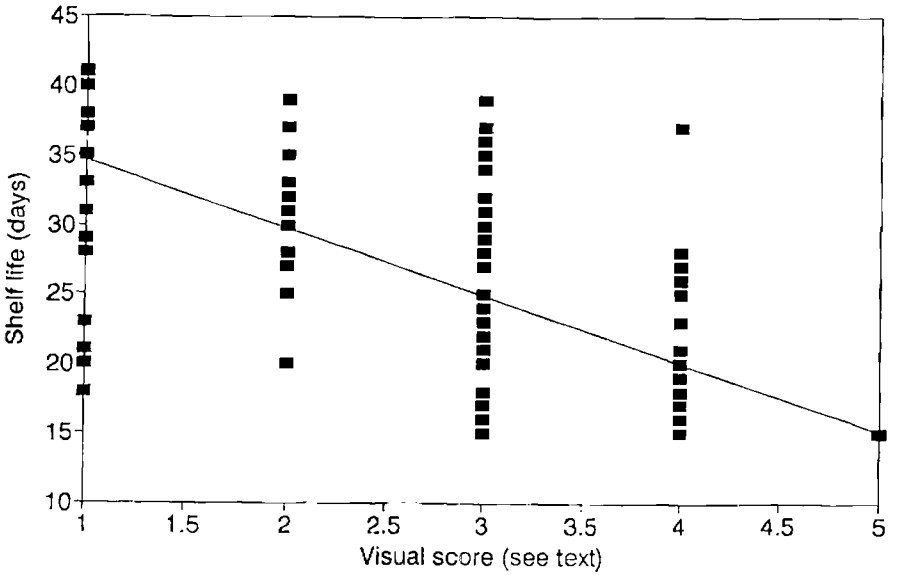

Fig. 3 . Visual score/shelf life relationship

CARIBBEAN EXPORT INDUSTRY FOR *HELICONIAS* - PROBLEMS AND PROSPECTS

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ABSTRACT

An assessment of the heliconia industry in the Caribbean was obtained through a survey of the major growers in Barbados, Guyana, Jamaica and Trinidad and Tobago using a pre-tested questionnaire. The objective of the survey was to establish the status of the industry and to identify technological approaches used in production and postharvest management. Approximately 90% of the growers surveyed cultivated less than one acre, the remaining 10% cultivated from 5 to 30 acres. The low levels of fertilizers and pesticides used by the smaller growers were associated with lower yields and lower quality blooms which were sold mainly on the local market. Larger growers used a higher level of technological inputs and were involved in the export trade mainly to Canada, USA and Europe. Among the major problems which limit the marketability of this species are short shelf life of some varieties and generally low tolerance of blooms to cold temperatures during transport from grower to market. The problems and prospects for the export industry for heliconias in the Caribbean are examined.

INTRODUCTION

The export of cut flowers has been recognized as one of the most promising potential growth areas for horticultural exports from the CARICOM region. One of the main reasons is that there are many exotic and attractive species which exist naturally in most Caribbean islands. Additionally, climatic conditions allow year round production and enable Caribbean countries to produce tropical plants for export. The proximity to markets and the existence of well developed air links between North America, and Europe and most of the islands are other definite advantages in the floriculture export trade. It is perhaps the recognition of these advantages that has led many CARICOM countries to include floriculture in their diversification programs. The major countries at present involved in floriculture exports are Barbados, Belize, Dominica, Grenada, Guyana, Jamaica, St. Lucia, St. Vincent and the Grenadines and Trinidad and Tobago. Despite this interest, the floriculture sector in the English speaking Caribbean is still underdeveloped and forms a small percentage of the total horticultural export from CARICOM.

CARICOM CONTRIBUTION TO WORLD TRADE IN CUT FLOWERS

The world trade in cut flowers has shown an increasing trend from 1984 to 1988 (Table 1). During the period 1984 to 1988 the value of cut flower trade had increased almost 100 %. The contribution of the area which included the Caribbean (other DGCS) had a small but steady increase.

Table 1. World trade in cut flowers (US$M).

YEAR	1984	1985	1986	1987	1988
VALUE	1253	1258	1682	2164	2455
ALL DGCS*	280	283	326	380	477
OTHER DGCS**	234	231	260	295	360

* DGCS Developing countries/areas
**Other DGCS includes the Caribbean
Source: Dynamics of exports from developing countries (1984-1988). International Trade Centre (1990).

According to a floriculture study done by Comite de Liason Europe - Afrique - Caraibes - Pacifique pour la Promotion des Fruits Tropicaux, Legumes de contre-saison, Fleurs, Plantes ornamentales et Epices (COLEACP), in 1991, floricultural exports from Central America and the Caribbean region (including Florida) amounted to US$346 million and showed an increasing trend. The value of the exports from African, Caribbean and Pacific countries amounted to only US $7.9 million, the majority of which worth US$ 5.4 million went to the USA and US $2.2 million to the European Union. The study indicated that the ACP countries could improve their share of the market particularly to the European Union. This region is particularly attractive because of its large population, approximately 353 million people.

CUT FLOWER IMPORTS INTO THE UNITED STATES

The estimated imports of tropical cut flowers into the United States from 1986 to 1989 also showed an increasing trend (Table 2). In 1986, there was no recorded import of heliconias into the United States of America. However, by 1987, heliconia imports were valued at US $ 0.1 million and continued increasing so that by 1989 the value of imports stood at US$ 0.5 $ million. In contrast, in 1989, *Dendrobium* orchids constituted more than 50% of the total import value of tropical cut flowers followed by gingers with approximately 24%.

Table 2. Estimated imports into the United States of tropical cut flowers (US$M).

PRODUCT	1986	1987	1988	1989
Anthurium	0.0	0.2	0.3	1.2
Ginger	0.1	0.2	2.0	3.0
Heliconia	0.0	0.1	0.2	0.5
Dendrobium Orchid	3.3	4.2	6.1	7.0
Protea	0.3	0.5	0.5	0.5
Bird of Paradise	0.1	0.2	0.4	0.6
TOTAL	3.8	5.4	9.5	12.8

This paper looks at the problems of the heliconia industry in the English speaking Caribbean with respect to production, marketing and postharvest management, and examines the prospects. A survey was conducted in Barbados, Guyana, Jamaica, Trinidad and Tobago. The major growers and exporters were interviewed using a pre-tested questionnaire. The results of this survey would be looked at in the process of examining the problems and prospects of the industry.

THE HELICONIA INDUSTRY IN THE CARIBBEAN

Commercial potential

The genus Heliconia belongs to the Heliconiaceae family and is closely related to bananas. The blooms are erect or pendulous terminal inflorescences composed of two or more bracts. The origin of this plant species has been traced to the tropical and sub-tropical rain forests of South America. It should be noted that the Caribbean region is within the area of origin.

It is believed that in the jungles of South and Central America there are probably more than 400 heliconia varieties (Berry, 1991). Of this number, only a few are grown commercially and the more important of these are shown in Table 3. Several criteria can be used to establish commercial potential. These include:

(i) Appearance - size and intensity of color

(ii) Rate of production of blooms

(iii) Year round production

(iv) Post harvest life - longevity

(v) Ability to withstand handling and shipping

For these reasons many varieties do not meet commercial criteria and therefore remain collectors items. Slightly different criteria may be used by some growers to determine a commercial bloom.

The post harvest retention of color and shape of the showy and attractive inflorescences of the heliconia contributes to its growing potential as a commercial cut flower.

Table 3. Important commercial heliconia varieties.

Heliconia sp	Common Names
H. psittacorum	Golden Torch Sassy Kaleidoscope St. Vincent Lady Di Nicoriensis
H. chartacea	Sexy Pink
H. chartacea purpurea	Sexy red
H. bihai	
H. caribaea	
H. jacquinii	
H. rostrata	
H. stricta	
H. wagneriana	
H. latispatha	

CURRENT STATUS OF THE HELICONIA INDUSTRY IN THE CARIBBEAN

In the survey conducted from March to August 1993, twenty-seven (27) heliconia producers in Barbados, Guyana, Jamaica and Trinidad and Tobago were interviewed. Table 4 shows the number of respondents in each island and the estimated acreage cultivated by each grower. This is by no means an exhaustive list but these growers were identified as the major producers and exporters. In Trinidad and Tobago these growers were obtained from the local Flower Exporters Association (FLEX) and the Extension Division of the Ministry of Agriculture Land and Marine Resources. The Guyana Marketing Corporation and the Ministry of Agriculture identified the Guyanese farmers

while Caribbean Agricultural and Research Institute (CARDI) Barbados did the same for Barbados. In Jamaica, Jamaica Promotions (JAMPRO) was responsible for providing the names of the growers and exporters there.

The survey was aimed at establishing the status of the heliconia industry in the English speaking Caribbean and identifying technological approaches used in production and postharvest management of the crop. Information was collected on various aspects including:

-size and source of planting material
-varieties grown
-pest and disease incidence
-fertilizer application
-harvesting techniques
-marketing
-export
-storage and postharvest treatment
-problems during production, postharvest and marketing

Despite the clear potential shown, there was a paucity of documented information on levels of trade. This was particularly so in the case of Jamaica where the different microclimates facilitate the production of several tropical and sub- tropical blooms which compete successfully with heliconia. Due to the small quantities exported relative to that of other blooms, heliconia was considered a minor export bloom and data on export and production were recorded together with other minor blooms . However, its growing importance has since been clearly recognized and both Jamaica and Trinidad and Tobago have decided to record heliconia export data separately from 1993 and 1992 respectively.

Production

Commercial heliconia production in the countries surveyed was found to be a viable activity. Similar varieties were produced in all 4 countries although the common names were different for some varieties. Export trade in all areas consisted of both small and large varieties. Blooms were sold not only locally, mainly to flower shops, but also to extra regional markets.

Table 4. Major heliconia growers surveyed and acreages cultivated.

Country	No of major growers surveyed	Total estimated acreage under cultivation
Barbados	4 L 1 S 3	26
Guyana	2 L 1	611/2
Jamaica	4 L 2 S 2	50
Trinidad & Tobago		
Trinidad	13 L 1 S 12	32
Tobago	3 L 0 S 3	1

L (large) >5 acres
S (small) <5 acres

Exports

Despite the general increases reported in the cut flower trade previously observed in both the World Trade (Table 1) and the imports into the USA(Table 2), available data from Trinidad, Barbados and Guyana indicate that their share in the market place is either decreasing or stagnant. The main export markets in order of importance were Europe, England, Canada and the USA.

Trinidad

Although the data from the Trinidad Export Development Corporation indicated that there were new markets for blooms from Trinidad in 1993, (Antigua, Montserrat, Switzerland and West Germany), the total quantity exported in 1993 decreased by approximately 22% from the 1992 figure (Table 5). Major exporters surveyed identified several production problems which contributed to the decline. Major ones are as follows:

(i) Increased incidence of moko disease which severely affected the cv Iris.

(ii) Low water availability during the dry season which restricted year round production. Increased production in the rainy season coincided with the summer months in which there is a low demand for blooms.

(iii) General low demand for psittacorums of which there is the perception of low shelf life. Nevertheless, the largest producer maintained a successful trade in psittacorums with long lasting varieties.

Table 5. Export of heliconias (kg) from Trinidad & Tobago 1992 and 1993.

COUNTRY	1992	1993
Canada	1054	345
USA	153	60
Montserrat	0	3
Antigua	0	26
Switzerland	0	1
W. Germany	0	1
TOTAL	1207	436

Barbados

Similarly, Barbados experienced a significant decrease in exports of heliconias between 1990 and 1993. There was an increase from 1991 to 1992 but a significant decrease from 1992 to 1993. The data reveals a fall in the export of psittacorums (Table 6) and "heliconias," which are large varieties as indicated by the Trinidad exporters.

Table 6. Export of heliconias (number of blooms) from Barbados 1990 - 1993.

	1990	1991	1992	1993
Heliconia	7,081	10,378	14,810	5,697
H.Rostrata	720	0	0	12
Psittacorums	4,572	1,955	2,642	1,970
Heliconia leaves	189	0	0	0
H.Wagneriana	0	0	110	92
Golden Torch	0	0	0	10
TOTAL	12,562	12,333	17,562	7,781

It should be noted that Barbados also found new markets for its cut flowers, mainly in Europe, Norway and Sweden (Table 7). From 1990 to 1992 the total value of cut flower exports from Barbados increased.

Table 7. Export of cut flowers and foliage from Barbados 1990-1992 (Bds $).

Country	1990	1991	1992
Canada	111,016	98,213	73,446
Finland	47,033	53,985	95,922
Germany	3,568	0	0
Norway	0	946	0
USA	198	0	0
Sweden	0	22,209	18,085
TOTAL	161,815	175,353	187,473

Guyana

The figures for Guyana (Table 8) indicate total cut flower exports. However, the survey revealed that there was only one major cut flower exporter from Guyana approximately 80% of whose exports consisted of heliconias. There was a significant increase from 1989 to 1990. There were no recorded exports for 1991 but the amount exported in 1992 did not decrease from the 1990 figure.

Table 8. Export of cut flowers from Guyana 1989-1992.

YEAR	KG
1989	381.82
1990	1745.45
1991	0.00
1992	1745.45

PROBLEMS

After discussions with the heliconia growers, several problems were identified as important to the industry . The most significant among them were:

(i) Bloom quality
(ii) Distribution costs
(iii) Marketing
(iv) Shelf life
(v) Nomenclature

Bloom Quality

A good quality bloom is one that has no blemish, is well formed and is uniform in color. It was pointed out at the COLEACP seminar held in Trinidad in May 1994, that the quality of a large percentage of the flowers produced in this region is below the required standard for the export market. Unsuitable production practices, for example inadequate or no fertilizer application and pest control, could be major contributors to this unacceptable quality.

Of the heliconia growers interviewed, 61.5% of them have never had a soil analysis done and 81.5% applied some degree of fertilizer. Applications range from a handful at planting to five bags (approximately 500 lbs) spread over 5 times per year.

The larger growers are the ones who export and the survey showed that they paid more attention to pest, disease control and plant nutrition. Pests and diseases e.g. borer, bacterial wilt, moko and fungus, were more a problem for the small grower than the larger ones. While 82% of the smaller growers indicated that they had pest and disease problems only 20% of the larger ones did. Pests and diseases could also reduce the quality of the blooms by discoloration or distortion. The large growers were also more likely to irrigate during the dry season to maintain production . The smaller growers mainly targeted the local markets and quality did not seem a high priority.

Distribution costs

One major problem highlighted by 95% of the exporters surveyed was the problem of the high cost of distribution. Information from the Market Study For Tropical Flowers in the United States done in November 1991 by the International Trade Center, indicated that the freight costs by road is generally less than 1/3 of bulk air freight costs. Approximately 70-75% of cut flower imports is routed through Miami, which is recognized as the center for the United States distribution. Flowers are then trucked to their final destination.

The study further pointed out that trucking companies in Miami generally operate with custom-designed temperature-controlled refrigerated trucks from modern and fully temperature controlled distribution centres. However, the majority of the floricultural imports consists of temperate flowers such as carnations, roses, and chrysanthemums. The quality of these flowers is maintained at 1 C - 2 C. All tropicals will incur damage at these low temperatures. The temperatures are generally set to accommodate temperate blooms and tropicals are given a low priority.

All heliconia exporters indicated that they ship their heliconias in corrugated cardboard boxes. Even with additional insulation, heliconias suffer cold temperature injury. The recommended storage temperature for heliconias is 15-20 C. Exporters therefore ship by the costly air route directly to the importer. The high cost of distribution significantly

increases the price of flowers to the retailer and ultimately the consumer.

Marketing of heliconia blooms

The survey data indicated marketing of blooms as a major problem, especially for the smaller growers. While these smaller growers were more or less confined to the domestic market, the larger producers had well established niche markets in foreign countries.

Burch (1992) reported that market opportunities for heliconias are limited to those existing highly specialist and professional producers who are able to provide a continuity of supply of high quality flowers.

A market study done in 1991 of the United States markets by the International Trade Commission indicated an over-production of most species of heliconias. The report indicated that given the high cost of distribution by air, and the major postharvest handling problems, extremely limited opportunities exist for any new entrant into the marketplace.

Shelf Life of heliconia varieties

There has been some concern expressed over the keeping quality of a number of heliconia varieties. The literature and the survey have shown that the natural shelf life of some varieties can be as little as three days e.g. *H.rostrata, H. stricta*, while others can last up to three weeks e.g. *H. wagneriana, H.chartecea*. The shelf life of these varieties can be shortened by unfavorable conditions during production and poor shipping and storage conditions.

Nomenclature

The survey revealed that the same variety may be called by different names in each island, as pointed out earlier. In the interest of the survival and expansion of the industry, it is desirable that the nomenclature be standardized. Growers now mostly use the nomenclature as set out by Berry (1991).

PROSPECTS

Markets

Solving the problems associated with marketing would lead to improved prospects for the heliconia industry. Heliconia growers should embark on sales promotion within the importing countries. It was the view of the COLEACP consultant that developing countries could substantially increase their market share by improving production and marketing techniques, sourcing better information on markets and contacts with importing countries.

Market strategies to be considered when attempting to increase heliconia sales include:

(i) bouquets
(ii) new varieties
(iii) collective marketing

Bouquets

Selling heliconias in bouquets with other tropical blooms has been recommended by some cut flower importers. Buyers from France and Germany at the COLEACP seminar at the Trinidad Hilton in May 1994, indicated that they would be more inclined to buy if foliages were sold along with the heliconia blooms. A range of products are apparently more attractive to the buyer.

New varieties

The possibility also exists of breaking into the market place with new varieties. It is anticipated that smaller volumes of a wide range of varieties will improve the marketability of heliconias. The varieties now exported have been in the market place for a long time and new exotic varieties would increase the appeal of the species.

Collective marketing

The Caribbean Development Bank in their study on the regional horticulture sector in Caricom States in 1987 recommended that both national and regional Flower Producers Associations be formed. These associations would be charged with establishing uniform quality standards for export and maintenance of members' accounts and records that reflect the quantities of flowers/plants received for export.

The growers themselves apparently recognized the importance of a unified regional approach to dealing with their problems. The Caribbean Floriculture Exporters Association was formed at the International Horticulture Trade Show, PLANTEC in Frankfurt Germany in 1993. The exporters realized that they had common problems in selling their blooms and that they needed to adopt a regional approach to these problems in marketing, production and promotion. The stated objective of the association was to enhance export marketing of regional cut flowers.

Since that inaugural meeting, the group has never met. The principal parties involved explained that it was too expensive to meet in the Caribbean since they each came from a different island. It is important that Caribbean growers cooperate so that they can attempt to solve some of their problems.

Research Needs

A method has to be found to protect tropical flowers from cold injury associated with the refrigerated road transport system upon which the USA temperate cut flower industry is based. Better packaging methods would be one of the areas to be examined. This would serve to reduce retail prices and possibly improve sales of heliconias. In Germany the trend is now to transport blooms in trucks with twin cabs each with a different temperature. Both temperate and tropical blooms can then be transported in the same truck.

As the survey showed, heliconia growers have no documented guidelines to follow for the production of the crop. It is clearly seen that fertilizer application and pest and disease control measures are done on an ad hoc basis. Research is therefore needed to establish the agronomic practices and produce technological packages for the efficient production of heliconias.

Continuous research should also be done to identify blooms with good lasting quality . Short shelf life has been listed as one of the limiting factors to the expansion of the industry. It is therefore important to develop blooms with an acceptable lasting quality. The criteria used by Costas Flores are probably quite adequate for commercial bloom selection.

CONCLUSION

The overall picture for the Caribbean heliconia industry could be greatly improved if Caribbean growers enhance their marketing techniques, obtain better information about markets and embark on promoting heliconias within importing countries. Research would lead to the selection of suitable cut flower types for export and the production of data on the cultural requirements of the crop.

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EFFECT OF KINETINE, FOLCISTEINE AND HUMIC ACID ON THE YIELD OF "JIRA" EGGPLANT (*SOLANUM MELONGENA* L.)

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ABSTRACT

The effect of spraying a cytokinin (*kinetin*) and two biostimulants (humic acid and folcisteine) on the yield of "Jira" eggplant was evaluated. The best yield response was obtained with folcisteine at 15 ppm, being significantly higher than the yield obtained with 7.5 ppm of the same product. Results were not significantly different at rates 7.5 and 3.75 ppm of folcisteine. The yields obtained in control plants and those treated with humic acid (7.5, 15.0 and 30.0 ppm), kinetin (200 and 400 ppm) and 3.75 ppm of folcisteine were not statistically different.

RESUMEN

Se evaluó el efecto de la aspersión de una citokinina (kinetina) y dos bioestimulante (ácido húmico y folcisteína) sobre el rendimiento de la berenjena "Jira". Los mejores resultados se obtuvieron al aplicar 15 ppm de folcsitcína, siendo significativamente diferentes a los rendimientos obtenidos en las demás dosis. No hubo diferencia significativa eb la productividad de las plantas tratadas con 7.5 ó 3.75 ppm de folcisteína. Los rendimientos de las plantas control y de las que recibieron los tratamientos de kinetina (200 y 400 ppm), ácido húmico (7.5, 15 y 30 ppm) y 3.75 ppm de folcisteína no fueron estadisticamente diferentes.

INTRODUCTION

Eggplant (*Solanum melongena* L.) is one of the most popular vegetables in the Dominican Republic. The area dedicated to this crop is close to 900 hectares per year. As in any other fruit-producing vegetable, the yield potential in eggplant is very high, and yield can be improved through a number of ways, including more effective plant protection, adequate plant nutrition and the use of plant growth regulators and plant stimulants.

A series of experimental works have been conduted and published in relation to the practical possibility of using this kind of compound to enhance yield and/or quality of eggplant in the Dominican Republic (Moscat, 1992; Morales-Payán, 1990; Morales-Payán, 1991; Morales-Payán, 1993) and other countries (Nickell, 1982; Nothmann, 1985), according to which folcisteine and (GA_3) have resulted in better yields.

Several commercial products containig humic acid, kinetine, and other active ingredients with regulatory effects have entered the agri-chemical market in the Dominican Republic, creating the need for the evaluation of their effectiveness as yield enhancers.

Folcisteine is a plant stimulant. Its mode of action is the activation of anabolic enzymes through the slow liberation of thiolic groups (-SH) and the action of those groups on enzyme molecules. The mode of action of humic acid has not been completely explained. There is some evidence that it also works at an enzymatic level. As with folcisteine, an overall plant stimulation is expected to be the effect of humic acid application. Kinetine is a cytokinin, working primarily on cell division. When applied to fruit-bearing plants, kinetine should promote cell division in the forming fruit, and thus induce the formation of larger fruits. The

objective of the experiments presented in this paper were to determine the effect of commercial products containing humic acid, kinetine and folcisteine on the yield of eggplant (Solanum melongena L.) "Jira" when applied during flowering, and to determine the best rates for yield improvement in the conditions of San Cristóbal, Dominican Republic.

MATERIALS AND METHODS

The experiment was conducted in the Central Experimental Station of the Centro Sur de Desarrollo Agropecuario (CESDA) (Southern Center for Agricultural Development) in the outskirts of the city of San Cristóbal, Dominican Republic. Three simultaneous field experiments were carried out side by side, to provide the same climatic, soil and technical management conditions. A ramdomized complete block design with four replications was used. "Jira", the major eggplant variety in the Dominican Republic, was used in all experiments. Plants were grown according to the technical recommendations for the crop in that region, and treatment was given when plants were in the full flowering stage.

Treatments consisted of single sprayings of aqueous solutions of either folcisteine (FOLC), humic acid (HUM) or kinetine (KIN) directed to the upper leaves and to the flowers. The rates tested were 3.75, 7.50 and 15.00 parts per million (ppm) for FOLC, 200 and 400 ppm for KIN, and 7.5, 15.0 and 30.0 ppm for HUM, and a control treatment. Commercial yield (weight of commercial fruits per area) was the only variable evaluated. Seven partial harvests were made during the experiments.

RESULTS AND DISCUSSION

The summarized results of the experiments are presented in table 1. Yield values are the added weights of the seven partial harvests.

According to these results, humic acid and kinetin had no signifficant effect on yield at any of the rates tested, showing yields statistically equivalent to those of the control plants. FOLC at rate 3.75 ppm did not significantly differ from the control or from FOLC at rate 7.50 ppm in terms of yield, although 7.50 ppm FOLC resulted in significantly higher yield than the control.

The best results for yield were obtained with 15.00 ppm of FOLC, being significantly superior than all the other treatments tested in these experiments. There are no previous reports of the effects of HUM or KIN on "Jira" eggplant for the comparison of results. Based on the results of our experiments, there seems to be no effect either product on the yield of this crop. Nevertheless, more rates of both compounds will be included in future research work to cover a wider range for possible response.

The results for FOLC are in agreement with those previously reported in "Jira" eggplant grown in the same area (Morales-Payán, 1990). The fact that the highest rates resulted in yields significantly higher than those of the control, and that the rate of 15.00 ppm was statistically better than the rate of 7.50 ppm, suggests the possibility that higher rates of FOLC might stimulate the plants to produce higher yields. A series of higher rates will be include in future experiments, with the objective of determining the maximum yield response of "Jira" eggplant to FOLC rates.

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Table 1. Effects of Kinetine, Folcisteine and Humic Acid on "Jira" Eggplant yield.

Treatment	Yield (Tons/Ha)
15.00 ppm Folc	a 9.12
7.50 ppm Folc	b 8.01
3.75 ppm Folc	bc 7.63
Control	c 6.82
200 ppm Kin	c 6.73
400 ppm Kin	c 6.70
30.0 ppm Hum	c 6.66
15.0 ppm Hum	c 6.62
7.5 ppm Hum	c 6.59

YIELD RESPONSES OF "BEN SHEMEN" ONION (*ALLIUM CEPA* L.) TO GIBBERELLIC ACID AND FOLCISTEINE APPLICATION

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ABSTRACT

An experiment was conducted to determine the effects of gibberellic acid (GA_3) and the biostimulant folcisteine on growth and yield of yellow onion (*Allium cepa* L.) "Ben Shemen" under the conditions of Santo Domingo, Dominican Republic. Application of 10 ppm GA_3 plus 10 ppm folcisteine gave the best results for bulb fresh weight, dry weight and diameter, which were significantly increased over those of control plants and the other combinations of the regulators tested.

RESUMEN

Se realizó un experimento para determinar los efectos del ácido giberélico (GA_3) y de la folcisteína en el crecimiento y el rendimiento de la cebolla amarilla (Allium cepa L.) "Ben Shemen" en las condiciones de Santo Domingo, República Dominicana. Los mejores resultados se obtuvieron con la aplicación de 10 ppm de GA_3 más 10 ppm de folcisteína, que incrementaron significativamente el peso fresco, el peso seco y el diámetro de los bulbos, comparados con los valores obtenidos con las demás combinaciones de los reguladores estudiados y respecto al control.

INTRODUCTION

In the Dominican Republic, onion is one of the major horticultural crops. Around 2000 hectares are dedicated to this crop every year. For yellow onion, which is used mostly for salads, the consumers prefer large diameters. From the producer's point of view, larger onions usually translate into more produce per area, increasing his income.

The biostimulant folcisteine, a folic acid and cisteine derivative that stimulates the activity of anabolic enzymes in plants, and the plant growth regulator GA_3 have been shown to improve the yield and/or the quality of several crops in the conditions of the Dominican Republic. At present, there are no documented experimental works about the use of either substance on yellow onion and their effects on this crop.

The objective of the experiments reported in this paper was to determine the possible effects of foliar sprays of GA_3 and folcisteine (FOLC), individually or combined, on the growth and yield of the "Ben Shemen" onion (*Allium cepa* L.).

MATERIALS AND METHODS

The experiment was conducted in Santo Domingo, Dominican Republic, It was performed two times, using a completely ramdomized design with six replications. "Ben Shemen", a yellow bulb cultivar of onion, was used. Individual plants were grown on sandy loam soil in plastic containers (15 cm height X 15 cm diameter), receiving the same nutrition, watering and pest/disease protection, following the recommendations for the crop. Treatment consisted of foliar spraying of GA_3 and/or FOLC at rates 0, 5, 10 and 15 parts per million (ppm) in water. The application of treatments

was done only once, 50 days after the emergence of the plants, when bulbing is initiated. The variables evaluated were bulb fresh weight, bulb dry matter, bulb diameter, bulb height, foliar dry weight and foliage length, measured at harvest.

RESULTS AND DISCUSSION

The effect of the combination treatments on bulb fresh weight and diameter are shown in tables 1 and 2, respectively. Bulb fresh weight was significantly higher in plants receiving 10 ppm of GA_3 plus 10 ppm of FOLC than in any other treatment; the combinations 15 ppm of FOLC plus 5 or 10 ppm of GA_3, and 10 ppm of FOLC plus 5 ppm of GA_3 resulted in bulb fresh weights statistically lower than the best treatment, but were significantly superior than the other combinations tested and the control. Neither GA_3 nor FOLC applied individually had significant effects on fresh weight or on any of the variables evaluated.

Bulb diameter was significantly larger in plants that received 10 ppm FOLC plus either 10 or 15 ppm of GA_3. Control plants and those receiving any of the other treatment combinations did not differ significantly in terms of bulb diameter. Bulb dry matter (data not shown) showed significantly higher values when plants were treated with 10 ppm of FOLC plus either 5 or 10 ppm of GA_3 than when treated with 15 ppm of FOLC plus either 5 or 10 ppm of GA_3. Bulb dry weight values recorded for control plants and those treated with the other combinations tested were not statistically different among themselves, but they were significantly lower than the combinations previously described.

Bulb height (data not shown) was significantly higher with the combinations 10 ppm FOLC plus either 10 or 15 ppm GA_3. No significant effect was found for the variables foliar dry weight and foliar length (data not shown). Folcisteine has been reported having a positive effect on growth and/or yield of different horticultural crops in the Dominican Republic, like eggplant (Morales, 1994b), green pepper (Valera, 1986), and radish (Morales, 1989), although it has produced significant differences in the yield of cabbage (Francisco, 1983), potato (Morales, Castillo and Vittini, 1990) or table beet (Morales, 1994a). There are no reports as to its effects in onions. As in other plant stimulants, response depends upon cultivar sensitivity, time of application, rate and climatic conditions. Its mode of action is the stimulation of the anabolic enzymatic processes, increasing enzymatic activity.

There are no reports of onion yield improvement by GA_3 application either. In the Dominican Republic, Alcántara-Suero (1994) did not find significant differences in yellow onion plantlets (in nursery) treated with several GA_3 rates. Pimentel and Encarnación (1994) did not find significant effects on red onion plantlets treated with GA_3 or a cytokinin. According to those results, onion is not responsive to GA_3 during its early growth. However, in experimental work done by Morales (1994c, 1994d) and by Morales and Cuello (1994) in the Dominican Republic with other Allium crops, GA_3 treatment has yielded promising results.

GA_3 mode of action is primarily by promotion of cell elongation and/or division, mainly in subapical meristems, although activity has been found in other tissues. Since individual applications of either GA_3 or FOLC did not produce significant changes in any of the variables evaluated, but the combination of both products at certain levels did have significant effects, there is a clear interactive effect of both compounds. The mode of action of this combination of stimulant-regulator remains to be elucidated.

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Table 1. Effect of Gibberellic Acid (GA3) and Folcisteine (Folc) on Bulb Fresh weight (g) of "Ben Shemen" onion.

FOLC (ppm)	GA3 (ppm)			
	0	5	10	15
0	102.45 c*	100.06 c	107.42 c	106.50 c
5	101.99 c	102.21 c	100.41 c	106.28 c
10	108.89 c	154.48 b	189.41 a	112.33 c
15	109.06 c	160.01 b	154.52 b	110.04 c

* Means followed by the same letter are not significantly different.

Table 2. Effect of Gibberellic Acid (GA3) and Folcisteine (Folc) on Bulb Diameter (cm) of "Ben Shemen" onion.

FOLC (ppm)	GA3 (ppm)			
	0	5	10	15
0	7.25 b*	7.29 b	7.28 b	7.31 b
5	7.41 b	7.40 b	7.41 b	7.42 b
10	7.39 b	7.33 b	7.75 a	7.72 a
15	7.32 b	7.29 b	7.36 b	7.33 b

* Means followed by the same letter are not significantly different.

COMPOSITIONAL CHANGES IN JAMOON FRUITS (*EUGENIA CUMINII*) DURING STORAGE

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ABSTRACT

Studies were conducted to evaluate quality changes in jamoon fruits using modified atmosphere packaging in conjunction with ethrel or ethanol treatments up to 12 days at refrigerated and non-refrigerated temperatures. Although ethanol was effective in reducing astringency in fruits after 3 days, fruits appeared bleached with sensory evaluations revealing a distinct off-taste which became intensified with increasing storage durations. Fruits stored in sealed low-density polyethylene bags on the other hand, maintained a turgid, fresh appearance and color with minimal changes in percentage fresh weight losses and decay after 12 days at 10°C without alterations in astringency.

INTRODUCTION

The jamoon fruit, botanically *Syzygium cuminii*, is a member of the Myrtaceae family. The fruit is known by English names such as Black Plum, Indian Blackberry, Jambul and Java Plum (Williams, 1969). In the East Indies where it originated, it is called by several local names such as Jaman, Jambu, Kala Jam, Phalani and Phalinda (Kirtikar and Basu, 1975).

The fruits are ellipsoid or oblong and about 1.5 to 2.5 cm long. They are borne in grape-like clusters, consisting of a mixture of fruits at the immature green stage to fruits at the mature purple stage. The fruits are used mainly for the making of wine, beverages and vinegar. Medicinally, the fruit is stated to be stomatic, carminative, antiscorbutic, and diuretic (Kirtikar and Basu, 1975). Cooked to a thick jam, it is eaten to allay acute diarrhoea (Kirtikar and Basu, 1975). It is rarely consumed as a fresh fruit because it is very astringent even when ripe. The ripe fruits are highly perishable and are thus difficult to handle and store. While some studies have been reported on the nutritional, medicinal and processing values of jamoon fruits (Williams, 1969, Khurdiya and Roy, 1985) there are no published data on the postharvest behavior of the fruit during storage. Additionally, efforts to reduce the astringency of the fruit could result in wider utilization as a fresh fruit and as a substitute for the importation of temperate fruits. In view of this, investigation focussed on the effects of modified atmosphere packaging and prestorage chemical treatments on the general quality and compositional changes of the fruit during storage in an attempt to improve its shelf life and palatability for human consumption.

MATERIALS AND METHODS

Fresh jamoon fruits were hand-harvested between 8:00 - 9:30 a.m. in East Trinidad, and transported in single layers in cardboard cartons to the laboratory in the Department of Crop Science, University of the West Indies within 45 minutes of harvest. Fruits were carefully and individually removed from bunches and graded in terms of apparent maturity, size, and color. They were then washed in a mixed fungicidal and bactericidal solution consisting of 500 ppm Bavistin FL and 500 ppm sodium hypochlorite plus a sticker (Tween 20, 0.1%) for 10 minutes. Fruits were selected a second time for consistency in size and color as well as to remove those that had any signs of

physical injuries such as punctures, bruises, abrasions or splits and surface dried in a single layer on absorbent soft paper for 35 minutes. A total of 1,080 individual fruits were then divided randomly into three equal portions.

Fruits were then subjected to the following pre-storage chemical treatments. The first batch was dipped into a solution of 300 ppm ethrel and 0.1% Tween 20 sticker for 10 minutes. The second portion was dipped in 95% ethanol for 2 minutes and the third portion was the undipped control.

Batches of ten fruits were randomly taken from each of the above treatments and seal-packaged in low density polyethylene (LDPE, 0.025mm thick) or high density polyethylene (HDPE, 0.025mm thick) bags, or left in open paper bags and stored at 10°C 70-80% R.H., 20°C 65-75% R.H. and 30°C 60-70% R.H. respectively. Fruits were assessed at 3 day intervals up to 12 days for the following parameters:

(i) Fresh weight losses, calculated as a percentage of the initial weight prior to storage.

(ii) Astringency score based on a hedonic scale from 1-5 with 1 = non-astringent, 2 = slightly astringent, 3 = moderately astringent, 4 = astringent and 5 = extremely astringent. This subjective evaluation was correlated with the ferric chloride test as previously conducted by Gazit and Levy (1963). The freshly cut surface of the fruit was pressed against dry filter paper that was previously soaked in a 5% ferric chloride ($FeCl_3$) solution. This resulted in the development of a purple-black color if the fruit was considered to be extremely astringent to a light pink color if the fruit was non-astringent. The varying intensity of color changes of the filter paper from pink to dark purple-black was used to develop a color chart to correspond to the degree of astringency as described previously.

(iii) The pH of the fruit was obtained by blending 12.5g of the pitted fruit in 50 ml of distilled water (Oster 8-speed blender) for 1 minute. The mixture was strained through a 0.5mm gauge strainer and the pH of the filtered liquid was determined using an Orion Research Expandable Ion Analyzer, Model EA920. The pH meter was standardized with buffer solutions at pH 2 and pH 7.41 respectively.

(iv) Total soluble solids (TSS) concentration was done by using a Bettingham and Stanley hand-held refractometer with a measuring range of 0-20% using the expressed juice and expressed as a percentage.

(v) Percentage decayed fruits were obtained by calculating the number of fruits per treatment showing visible signs of pathological infections.

(vi) Microbial analysis was done by aseptically isolating microorganisms from the decaying fruits on commercially prepared Oxoid Potato Dextrose Agar (PDA) for yeast and mould, and Oxoid Nutrient Agar (NA) for bacteria using the Direct Streak technique. Both the PDA and NA media were prepared for inoculation by rehydration with distilled water followed by sterilization in a Prestige 4-quart pressure cooker at 121°C and 15 psi for 15 minutes. After cooling at 50°C, 15ml aliquots of each medium were poured into sterile Pyrex glass petri dishes and allowed to cool before inoculation. The petri dishes containing the inoculated media were then incubated aerobically at 25°C for 48-72 hours in a Gallenkamp Size 2 Model INA 300-130M incubator. The yeast and bacterial colonies isolated were then stained using Grain stain method, while the moulds were mounted on glass slides and fixed under a cover-slip in lactophenol cotton blue solution. All of the isolated organisms

were examined using a Bauch and Lomb microscope for identification of micro-organisms.

(vii) Fruits were classified into one of four chilling injury categories where 1 = no injury; 2 = slight; 3 = moderate (limit to marketability); 4 = severe with extensive secondary infections. The chilling injury index was determined for each fruit by summing the products of the number of fruits in each category and then dividing this sum by the total number of fruits asessed (Wild and Hood, 1989).

The experiment consisted of four replicates. Data were analyzed as a completely randomized design with a factorial arrangement of variables, and significance tested by the F-test and L.S.D. where applicable after transformation for ranking (Sneddor and Cochran, 1980).

RESULTS AND DISCUSSION

The results in this study indicated that jamoon fruits stored best at 10°C when seal-packaged in LDPE bags having the lowest percentage of decayed fruits after 12 days when compared to decay incidence in fruit stored in HDPE or paper bags (Table 1). Dipping fruits in ethanol was most effective in reducing fruit astringency after 3 days with a steady decline as storage time increased (Figure 1). Despite the reduction in astringency, a slight alcoholic-taste was detected but this was objectionable after 9 days and more so at the two higher temperatures where fruits were seal-packaged in the two types of polyethylene packaging. Ethanol-treated fruits appeared bleached with fruits having a lighter purple color compared to the normal dark purple color. Ethanol probably dissolved some wax on the fruit epidermis thus reducing the normal gloss associated with these fruits. In some cases ethanol promoted fruit-splitting which contributed to the occurrence of secondary infections. Apparently the ethanol treatment was more effective than the other chemical treatments because it promoted a faster conversion of the astringent tannins from a soluble to an insoluble form as fruits become non-astringent, although the fundamental change in tannins leading to insolubility and the mechanism initiating this change is not known (Eaks 1967, Gazit and Levy 1963, Overholser 1927). In other studies, Gazit and Levy (1963) and Eaks (1967) obtained similar results in terms of improved palatability when persimmons were treated with 95% alcohol.

Several studies have shown ethrel as an effective remover of fruit astringency (Rosa, 1925; Chase and Denny 1924). The limited success of ethrel in this study could be related to the duration of application and the type of fruit. Perhaps the 10 minute dip was too short compared to the 15-24 hours exposure given to other fruits as reported by the authors cited above. Ethrel did promote fruit ripening accounting for higher total soluble solids after 12 days at 10°C compared to the other treatments (Table 3). The higher ($P<0.05$) total soluble solids for fruits in paper bags could be attributed to the loss of moisture and the resultant concentrating of sugars.

While it is obvious that the microsaturated environment and modified atmosphere created within the sealed bags would have accounted for the lower fresh weight losses and extended shelf life for fruits in LDPE and HDPE bags (Table 2) compared to fruits kept in paper bags it was also evident (Figure 2) that this may have also accounted for a reduction in chilling injury. In other studies Ben-Yehoshua *et al* (1983) and Mohammed *et al* (1990) obtained similar results although both groups of authors agreed that HDPE bags was more effective than LDPE bags in reducing chilling injury. In this study both polyethylene bags had similar effects on chilling injury (Figure 2). The higher degree of desiccation of fruits in paper bags compared to LDPE and HDPE bags contributed to a significant ($P<0.05$) reduction in decay (Table 1). The causal organism of decay for fruits in LDPE and HDPE bags were species of the Genus *Mucor*.

Further investigations are continuing to determine alternative methods for removal of fruit astringency and extending shelf life using perforated and non-perforated polyethylene bags.

Table 1. Effects of M.A.P. and Chemical Treatments on % Decayed Jamoon Fruits after 12 days at 10°C.

AFTER 12 DAYS AT 10°C			
CHEMICAL TREATMENTS	% DECAYED FRUITS		
	LDPE	HDPE	PAPER BAGS
ETHREL	26.1 bc	30.9 d	100.0 g
ETHANOL	18.4 a	23.2 b	90.4 f
CONTROL	23.5 b	28.4 cd	86.9 e
LSD (0.05)		±3.2	

Table 2. Effect of packaging upon percentage fresh weight losses of jamoon fruits during storage.

FRESH WEIGHT LOSSES (%)				
PACKAGES	3 DAYS	6 DAYS	9 DAYS	12 DAYS
LDPE	7.99 ab	8.40 ab	9.76 bc	11.14 c
HDPE	7.45 a	8.20 ab	8.52 ab	10.11 bc
PAPER BAGS	20.74 d	32.59 e	38.02 f	47.74 g
LSD (0.01)		±2.15		

Table 3. Effects of packaging and chemical treatments on pH and T.S.S. in Jamoon after 12 days at 10°C.

AFTER 12 DAYS AT 10°C						
CHEMICAL TREATMENTS	pH			T.S.S.		
	LDPE	HDPE	P.BAGS	LDPE	HDPE	P.BAGS
ETHREL	2.84 bc	2.85 c	2.83 bc	11.78 d	11.44 c	13.11 f
ETHANOL	2.80 a	2.82 ab	2.80 a	10.69 b	10.36 a	12.03 d
CONTROL	2.83 bc	2.84 bc	2.83 bc	11.19 c	10.86 b	12.53 e
LSD (0.01)		±0.02			±0.25	

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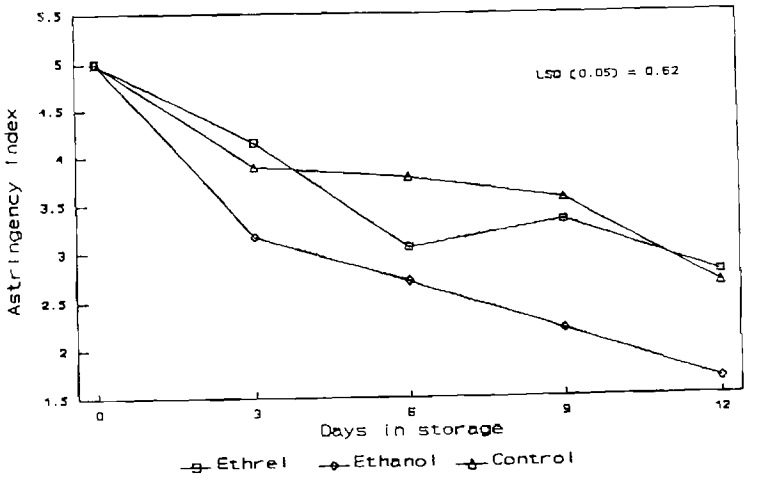

Fig. 1. Effect of chemical treatment on th removal of astringency in Jamoon fruits.

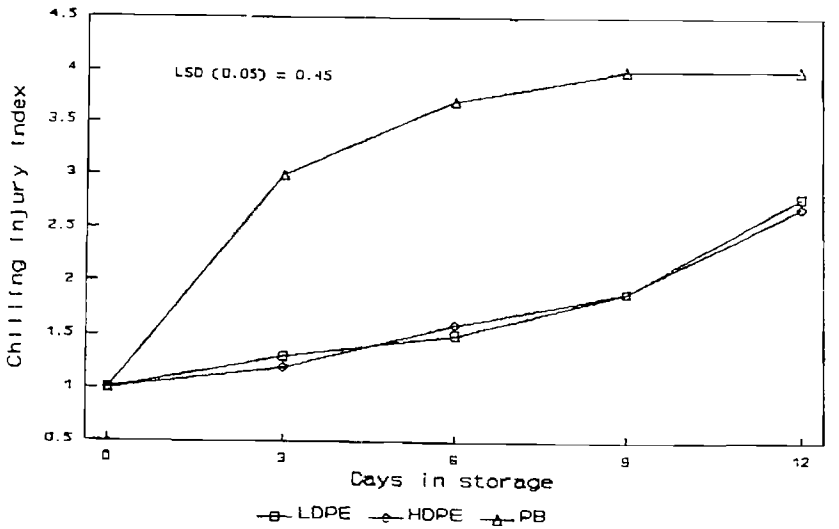

Fig. 2. Effect of packaging upon chilling injury in Jamoon fruits.

POSTHARVEST STORAGE OF THE POMERAC UNDER REFRIGERATION

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ABSTRACT

A postharvest storage trial was conducted to determine the effects of four different storage temperatures, ambient (28°C), 5°C, 10°C and 15°C on the shelf-life of the pomerac (Eugenia malaccensis) or French Cashew. The aim of the experiment was to determine the best storage conditions for extending the shelf-life of the pomerac, while maintaining acceptable physical, chemical and organoleptic properties. The physical parameters measured included fruit firmness, percent fresh weight loss and specific gravity. The chemical parameters studied were ascorbic acid, titratable acidity, total soluble solids, pH and anthocyanins. Sensory measurements included color, firmness, odor, decay and shrivelling. Preliminary results showed that under ambient conditions the pomerac had a shelf-life of 4-6 days. Fruits held at 10°C and 15°C were shrivelled, decayed and showing color loss in the skin after 10-15 days in storage. At 5°C fruits were acceptable in terms of color, firmness, taste and odor even after 20 days in storage.

INTRODUCTION

The fresh fruit of pomerac like the breadfruit and other tropical fruits, is generally known to have a short storage life of 4-6 days after harvest. The pomerac is considered acceptable when fully mature- ripe, but as soon as the fruit begins to soften it is considered inedible. This creates handling problems even in the local market. Additionally, postharvest handling is complicated by the fruit's thin epidermis, thus causing the fruit to be easily damaged.

Refrigerated storage is an effective means of prolonging the postharvest life of many fruits (Campbell, Huber and Koch, 1989). General commercial practice has been to store tropical fruits at 10°C or higher to avoid possible chilling injury (Campbell, Huber and Koch, 1989).

Important quality attributes for pomerac as with carambola fruits (Campbell, Huber and Koch, 1989) include size, color and taste, the latter being described generally in terms of sweetness and acidity.

At present there is little information on the postharvest behavior of the pomerac and consequently the objectives of this study is to evaluate the postharvest behavior of the pomerac under refrigerated were 5°C, 10°C and 15°C and ambient conditions 28°C.

MATERIALS AND METHODS

Firm, red ripe pomerac were harvested from the fields of El Carmen Research Station in St. Helena in Trinidad and transported to the Agricultural Processing Laboratory of the faculty of Engineering, University of the West Indies. The indicies used to determine harvest quality included firm, red, ripe fruit which are free of blemishes, pests and diseases.

The fruits selected were those that showed minimal signs of external blemishes or excessive bruising and fruits of similar size and color. These fruits were washed with tap water and air-dried. The fruits were randomly selected, wrapped with household tissue paper and packed

into cushioned, ventilated, cardboard boxes. The fruits were stored at four (4) different temperatures; 5°C, 10°C, 15°C and 28°C (ambient).

On the day of harvest, four fruits were selected for evaluating percent fresh weight loss (as a % of the loss in weight over the initial weight) Specific gravity was calculated from weight and volume determinations. Firmness was measured objectively using a Seta Penetrometer, with a cone and a 50 gram weight. The penetration depth was measured in millimeters after a period of 5 seconds with the depth of penetration being inversely proportional to firmness. Total soluble solids (TSS) in Brix % was measured with an Abbe Refractometer using a 1:1 dilution of pomerac pulp to water. Titratable Acidity was estimated as the percent citric acid content, determined by the titration method with 0.1N sodium hydroxide to a pH of 8.1-8.2. pH of a 1:1 dilution of pulp to water was measured using a pH meter (Analytical Measurement, model 707). Anthocyanin determination was measured using a 0.1N methanol-hydrochloric acid extraction process and color measured at 535 um wavelength using the spectrophotometer. Pulp color was also rated on a scale of 1 to 5 as follows: 1: white, 2: white with signs of cream, 3: light cream, 4: cream, 5: yellow.

Shrivelling was rated as follows: 1: none, 2: slight, 3: moderate, 4: severe.

At two day intervals, four fruits stored at 28°C and at five day intervals, four fruits from each of the other three temperatures were removed from their respective storage environments and evaluated for the above mentioned parameters. All results were statistically analyzed by the Analysis of Variance Method (ANOVA).

RESULTS AND DISCUSSION

Weight Loss

The weight loss (%) of Pomerac in storage was significantly affected by storage temperature($P< 0.05$). Weight loss increased with time for all treatments(Fig. 1). Under ambient conditions(28°C), there was a rapid increase to 36.6% after 8 days in storage.

At 15°C, the rate at which weight loss occurred was less than under ambient conditions and as shown in Figure 1, the rate was considerably reduced at 5°C and 10°C compared to both 15°C and ambient.

The result is expected since weight loss is attributed principally to water lost through transpiration and dry matter losses through respiration and both of these processes are retarded as storage temperatures are reduced.

Specific Gravity (S.G.)

The specific gravity of the freshly harvested Pomerac fruits prior to storage averaged 1.14. However, during storage, the specific gravity changed significantly and these changes(Fig. 2) were affected by the storage temperature($P<0.05$) and storage time($P<0.01$). The specific gravity of fruits stored under ambient conditions showed an increase to 1.20 after 8 days in storage(Fig. 2). At 15°C the S.G. increased to 1.35 after 15 days. Fruits stored at 10°C had a S.G. of 1.43 after 25 days and at 5°C the S.G. was 1.46 after 30 days in storage.

These results indicated an increase in denseness of the fruit, especially those stored at 10°C and 5°C. This may be attributed to a greater reduction in volume compared to that of weight, with time.

This fruit shrinkage, above that normally associated with transpiration, is possibly attributed to an overall reduction in fruit volume due to thermal contraction of the fruit cells with storage at low temperature(5°C and 10°C).

FIRMNESS

The firmness of the stored fruits was significantly affected by storage temperature($P<0.05$)and storage time($P<0.05$). Firmness of the fruit is inversely proportional to the penetration depths recorded by the penetrometer. Fruits stored under ambient conditions showed a gradual decrease in penetration depth. This was also observed at 15°C and 10°C (Fig. 3). When freshly harvested, the fruits had a penetration depth of 5.8 mm. After 8 days at ambient, the penetration depth was 5.5mm For fruits stored at 10°C, the penetration depth after 25 days was 3.4 mm and for 15°C, 5.1mm after 15 days in storage. However, for fruits stored at 5°C, fruit firmness appeared rather steady up to 25 days in storage, beyond which time, considerable softening was observed (Fig. 3).

The increase in fruit firmness in storage may be attributed to the fact that as the fruit lost excessive amounts of moisture (Fig. 1), the skin and flesh became tougher and thus the penetration depth reduced.

Fruits stored at 5°C had less moisture loss (Fig. 1) and the fruits remained supple and turgid for most of the storage period, with a rather constant firmness, until over ripening occurred beyond 25 days.

SUGAR/ACID RATIOS

The general trend for the sugar/acid ratio of Pomerac fruit was that it increased with storage time. However, fruits stored under ambient conditions showed a slight increase in the sugar/acid ratio, but at day 6 it decreased to 4.5 by day 8 (Fig. 4). At 10°C and 15°C°C, fruits' sugar/acid ratio increased from 3.6 and 3.8 respectively to 16.2 and 13.4 respectively. Fruits stored at 5°C, showed the highest increase in ratio where by the sugar/acid ratio rose from 3.6 to 18.9 by day 30 (Fig. 4). This increase in the sugar/acid ratio is attributed to the increase in Total Soluble Solids and the decline in acidity which was observed for fruits held at 5°C, 10°C and 15°C. Under ambient conditions, an initial increase in Total soluble solids (TSS) was also observed but this was followed by a rapid decline in TSS. This may have been due to the onset of decay of such fruits, with microbial metabolism of the sugars present.

COLOR

Prior to storage, freshly harvested fruits exhibited a bright red skin colour and during storage this was significantly affected by temperature ($P<0.05$). Color was determined through the measurement of Anthocyanins in the skin. Under ambient conditions, the intensity of anthocyanins increased from 0.243 um to 1.400 um after 6 days. But by the 8th day, the red color began fading thus giving a reduced intensity reading of 0.572 um for anthocyanins (Fig. 5). Fruits held at the 3 temperatures 15°C, 10°C and 5°C showed signs of color fading with time. At 15°C, the skin color went from a bright red to a faded pink/tan color after 15 days in storage. This was evident by the intensity reading which went from 0.243 um to 0.078 um (Fig. 5).

At 10°C, the skin color darkened from bright red to a dark red after 15 days in storage, but the colour began fading and eventually turned light pink by day 25 (Fig.5). The skin color of fruits held at 5°C went from bright red to faded light pink with traces of a tan color after 30 days in storage with an intensity reading of 0.092 um (Fig. 5).

This apparent color fading of the red pigment anthocyanin, maybe attributed to the breakdown of the red pigment when there is a change in the pH of the fruit. As the pH increases, the red pigment is altered to a blue pigment thus giving the faded blue pink colour (Asen, 1975; Paull, Deputy and 1985).

Pulp color was subjectively measured and appeared to be significantly affected by temperature ($P< 0.05$) and storage time ($P< 0.05$). When freshly harvested, the pulp of the Pomerac is white in color. At 10°C, the pulp went from white to a cream color after 25 days in storage. After 15 days,

those fruits stored at 15°C had a pulp color rating of 3.6, corresponding to a light cream color. Under ambient conditioned, the pulp was white with slight signs of cream after 8 days.

Those fruits stored under 5°C showed the least amount of discoloration to the pulp, with a rating of 2.3 (white with signs of cream) after 30 days in storage (Fig. 6).

SHRIVELLING

Shrivelling was seen to be significantly affected with time ($P < 0.01$) in storage. Fruits held at all the treatments showed some degree of shrivelling (Fig. 7). Fruits stored under ambient conditions showed severe shrivelling after 8 days. Fruits held at 15°C and 10°C showed moderate shrivelling in storage. After 30 days in storage, fruits held at 5°C showed moderate shrivelling. Shrivelling caused by moisture loss from the fruits can be related to the results from fresh weight loss (Fig.1). Excessive moisture loss at 28°C corresponds to the severe shrivelling that occurred. As the fruits lost moisture at the other three temperatures (15°C, 10°C and 5°C) the degree of shrivelling increased with time.

CONCLUSION

Pomerac held under ambient conditions (28°C) had a shelf-life of only 4-6 days. Fruits held at 10°C and15°C were shrivelled, decayed and showing color loss in the skin after 10-15 days in storage. At 5°C, fruits were acceptable in terms of color, firmness, and taste even after 20 days in storage.

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YIELD LOSSES IN COCONUT DUE TO THE ERIOPHYID MITE (*ERIOPHYES GUERRERONIS*)

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ABSTRACT

Tests were carried out on Maypan and Malayan Dwarf coconut varieties in two ecological zones, to assess the yield loss of copra due to the mite, *Eriophyes guerreronis* Keifer (Acarina: Eriophyidae). The results show a significant decline in copra output with increased mite damage ($p<0.001$). Total copra losses ranged from 4-5% but may be higher than 80% in the most severely damaged fruit.

INTRODUCTION

The coconut mite, *Eriophyes (Aceria) guerreronis* Keifer (Acarina: Eriophidae) is a microscopic organism that breeds under the perianth of the fruit of coconut (*Cocos nucifera*) where it feeds on the epidermal cells of the meristematic region. Occasionally it feeds on the apical meristem of the seedling.

The earliest symptom of damage is the appearance of white streaks originating from beneath the perianth. These regions enlarge and eventually become brown and corky. As the fruit grows in size the rapid cell division of the surrounding cells causes much stress in the damaged areas. This results in the development of deep fissures in the pericarp known to be characteristic of mite damage. In extreme cases, up to 80% surface area may be damaged. The result is great distortion and reduction in fruit size and a consequent decline in copra output (Julia and Mariau 1979; Hall, 1981; Anonymous 1985).

Although the mite was known to be in Jamaica since 1941 (Hall, 1981), it did not arouse serious concern until 1972 (Coconut Industry Board, 1973; Hall, 1981). Since then, the mite damage on coconut has been observed islandwide (Hussey, 1975). However, there has not been any previous attempt to quantify damage in terms of copra loss. Pesticides have been used without adequate information and there is no available record of the actual economic status of the pest in Jamaica.

Crop loss may be categorized according to the stage at which it occurs: pre-harvest, at harvest or post-harvest. Losses in coconut yields occur at all three stages. Losses during pre-harvest and harvest may be due to the death of plants, or loss of immature fruit resulting from pests, diseases, natural catastrophes, or praedial larceny. Normally small nuts are not bought by farm gate purchasers and heavily scarred nuts are too difficult to husk. If reaped, these nuts may be sold to copra factories at much reduced prices and in some cases, labor cost will exceed sale costs. Post harvest losses will occur during storage and may result from theft or infestation by pests and diseases.

Chiarappa (1971) observed that many estimates of crop losses have been made, but very few were realistic assessments in terms of actual quantity or quality. The objectives of this study are to quantify the effect of mite damage on copra yield and to determine whether the effect of mite damage on copra output varies with variety and site.

MATERIALS AND METHODS

This assessment was made during the harvesting period and was carried out on both Maypan and Red Malayan Dwarf coconut varieties on two farms in each of the parishes of Portland and St.

Mary. These farms were well managed with recommended levels of fertilizer being applied to the coconut trees which were grown in pure stands. The sections within these parishes from which data were obtained represent distinct ecological zones. The Portland site has a higher average annual rainfall (3,000-3,500 mm/annum) than the St. Mary site (<2,000 mm/annum).

The harvested fruit were grouped according to the extent of external mite damage using a modified scale for visual assessment (Julia and Mariau, 1979; Moore *et al*, 1989):

Grade 1 - fruit with no mite damage,
Grade 2 - fruit with up to 30% mite damage,
Grade 3 - fruit with 30-60% mite damage and less than 20% reduction,
Grade 4 - fruit with 60-80% mite damage, 20-30% reduction and with some distortion,
Grade 5 - fruit with over 80% mite damage, over 30% reduction and often greatly distorted.

The total number of fruit observed in each damage category was counted. A sample of five fruit was taken from various sections of the farm in each damage category for further processing. Each nut was labelled and taken to the laboratory where it was husked and the nuts broken to remove the endosperm. The endosperm was then weighed and placed in a kiln at 70°C for approximately 18 hours when the moisture content was at an average of 6%. The dry (copra) weight was taken.

The effects of mite damage (grade), variety, site and their interactions on copra yield were analyzed with the use of regression analyses. For the tabulated summaries, the copra yield within each category was estimated by multiplying the average copra yield per nut in the sample for each category by the total number of nuts within that group. The total copra yield of the harvested nuts was calculated by summing these copra yields. The percentage copra loss was estimated in the following way:

$$\text{percentage loss} = \frac{\text{potential yield - actual yield}}{\text{potential yield}} \times 100,$$

where the copra yield of the least damaged nuts' was used as potential yield.

RESULTS

There was a significant decline in copra output with increased mite damage ($p<0.001$). Generally, copra yield for Maypan was significantly higher than that of Red Malayan Dwarf ($p<0.001$), but the decline due to the mite was evident and similar for both varieties ($p=0.243$). See Fig. 1. There was no significant difference in the decline of copra yield with increased mite damage between the two sites, Portland and St. Mary ($p=0.070$). These results are summarized in Tables 1a,b.

EFFECT OF MITE DAMAGE ON COPRA YIELD

DAMAGE GRADE	MAYPAN	RED MALAYAN DWARF
1	213.03	160.48
2	226.1	149.81
3	172.37	119.79
4	108.26	60.21
5	55.83	27.94

Fig. 1. Effect of Mite Damage on COPRA Yield.

Table 1A. Copra Loss Assessment in Maypan Coconut at St. Mary and Portland, 1992-93.

Parish	Damage Grade[1]	Number of Nuts	Copra Yield/nut (g)	Copra Yield (kg)	Copra Loss (%)
St Mary	1	477	223	106	0[2]
	2	1391	248	345	0[2]
	3	339	190	64	22
	4	30	98	3	59
	5	2	68	<1	72
	Total	2239	232	518	4
Portland	1	298	206	61	0[2]
	2	472	210	99	0[2]
	3	134	160	21	23
	4	19	116	2	44
	5	0	-	0	-
	Total	923	199	183	4

Notes:
[1]Grade 1 Fruit with no mite damage.
Grade 2 Fruit with up to 30% mite damage.
Grade 3 Fruit with 30 to 60% mite damage and less than 20% reduction.
Grade 4 Fruit with 60 to 80% mite damage, 20 to 30% reduction and with some distortion.
Grade 5 Fruit with over 80% mite damage, over 30% reduction and often greatly distorted.

[2]The copra loss for these two categories was not estimated as both these were used as a baseline from which to determine copra loss.
- No nuts were found in this category.
Standard deviation for copra yield/nut (g) is 31.0.

Table 1B. Copra Loss Assessment in Red Malayan Dwarf Coconut at St. Mary and Portland, 1992-93.

Parish	Damage Grade[1]	Number of Nuts	Copra Yield/nut (g)	Copra Yield (kg)	Copra Loss (%)
St Mary	1	347	144	50	0[2]
	2	911	151	137	0[2]
	3	296	132	39	8
	4	41	53	2	66
	5	5	22	<1	84
	Total	1600	143	228	4
Portland	1	425	173	73	0[2]
	2	848	149	126	0[2]
	3	205	111	23	29
	4	20	65	1	68
	5	4	32	<1	80
	Total	1502	149	223	5

Notes:
[1]Grade 1 Fruit with no mite damage.
Grade 2 Fruit with up to 30% mite damage.
Grade 3 Fruit with 30 to 60% mite damage and less than 20% reduction.
Grade 4 Fruit with 60 to 80% mite damage, 20 to 30% reduction and with some distortion.
Grade 5 Fruit with over 80% mite damage, over 30% reduction and often greatly distorted.

[2]The copra loss for these two categories was not estimated as both these were used as a baseline from which to determine copra loss.
Standard deviation for copra yield/nut (g) is 31.0.

DISCUSSION

Most information found on yield reduction in coconut is not based on actual data. Julia and Mariau (1979), Mariau (1977, 1986) and Moore *et al* (1989) are among the few authors who have carried out research on actual quantitative losses in coconut yields due to premature fruit fall or reduction in copra production due to *E. guerreronis*.

Julia and Mariau (1979), studied the copra loss in two varieties (West African Tall and P-B 121 hybrid) using four damage categories. The average copra loss for the two varieties were 10, 30, and 45% in categories 2, 3, and 4, respectively. Mean copra yield loss was approximately 15% for the West African Tall and 7% for the P-B 121 hybrid varieties. Moore *et al* (1989) studied copra yield loss at five sites in St. Lucia over two years and found it to vary with space and time. Yield loss ranged from approximately 11-32%.

The results of this experiment have shown that the mite significantly reduces copra production. At both sites (St. Mary and Portland), copra loss may be as high as 80% in fruit found in the fifth damage category. However, these nuts comprise less than 1% of the total fruit produced. Fruit with least mite damage (i.e. those in grades 1 and 2) accounted for 79 to 85% of all fruit. Hence, the overall copra yield loss ranged from 4 to 5%.

Copra loss due to mite damage in Jamaica is subject to variability. Similar experiments have shown yield losses to range from 1 to 9% (McDonald *et al*, 1992). All these results are representative of the larger coconut farms which receive fairly good management. Relatively higher infestation levels have been observed on several small farms (McDonald and Alam, 1991).

Over the last two decades, the progress of distribution of *E. guerreronis* throughout the tropical and sub-tropical regions has been far reaching. This is largely due to wind currents which have aided its long distance migration. During this period several methods of control have been tested and/or proposed against the mite with varied success. These include chemical, physical, cultural and biological control methods.

Moore *et al* (1989) suggested that improved farming practices, combined with resistant varieties, could result in marked increases in crop yields. It was also found that yields were higher where coconut was intercropped with banana (Moore *et al*, 1989). This resulted from the positive response of the plant to the fertilization of the banana intercrop and the acaricidal property of the oil spray applied to banana. Mariau (1986) found copra loss to decline with irrigation and suggested that periods of moisture stress retard nut growth, when, meristematic tissue is subjected to extensive mite damage. Sarangamath *et al* (1976) further proposed that copra yield was dependent on various factors, including, variety, age of palm, soil, climate of the area, maturity of the nuts, seasons of harvest and period of storage.

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[1]Least damaged nuts are defined as those belonging to grades 1 and 2. As the copra yield per nut for grade 2 nuts was sometimes higher than that for grade 1 nuts, the weighted mean copra yield per nut for both grades was used as the potential copra yield per nut.

Therefore, there is need for further work to develop an integrated system of management of the coconut mite. This should include an evaluation of these methods to ensure that they are cost effective and sustainable. Any viable integrated pest management system for *E. guerreronis* should involve the use of cultural practices and resistant varieties to delay the establishment of the mite as well as the use of effective biological control agents to suppress the mite population.

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AGRICULTURE & ECONOMIC DEVELOPMENT

THE CHANGING STRUCTURE OF CARIBBEAN FOOD IMPORTS: AN INDICATOR OF DOMESTIC AGRICULTURE PRODUCTION OPPORTUNITIES

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Beginning with Rostow, patterns of development or stages of growth across countries and over time have been derived and used to define the changing structure of production and employment. More specifically, consumer demand theory, through the income elasticity of demand, has been identified as playing the role of catalyst in causing these structures to change. One of the simplest examples is the fact that, as income rises, certain foods are consumed in greater proportion to the total food budget, while others decline. For example, potatoes are known as an inferior food. As income increases, their consumption declines. More generally, as income rises, the proportion of income spent on processed food grows. A portion of this structural change is derived from relative price movements, but tastes are likely to be the dominant factor. With knowledge of the above, it becomes possible for the entrepreneur to forecast changes in the structure of food consumed in a country as income increases. Hence, decisions on profitable agricultural enterprises may be made with greater certainty. In a word, the changing structure of food consumption is an indicator of food production and processing opportunities. In this paper, an attempt is made to closely examine detailed food commodity imports to Caribbean countries from the United States for the period 1982-1993 to discover indicators of an evolution in the structure of food consumption as income grows. Estimates of this changing structure will be drawn from a sample of Caribbean countries using annual U.S. export statistics provided on a by-country and by-commodity bases. Conclusions will be drawn regarding the likelihood that such information may be used as an aid to business planning for profitable enterprises and for governments to use in the promotion of domestic business activities as substitutes for imports.

STRUCTURAL ADJUSTMENT IN TRINIDAD AND TOBAGO AND THE FUTURE OF AGRICULTURE

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The need for structural adjustment in Trinidad and Tobago was precipitated by the collapse in oil prices in 1986 and reduced production of oil. Borrowing, during the period of the oil boom, used in the construction of energy based industries--iron, steel, ammonia, urea and methanol--and for infrastructure development--modern telephone system, expansion in electricity capacity is now having to be repaid, in a situation of considerably reduced foreign exchange earnings and reduced government revenue. Successive devaluations of the currency have occurred, ending in a managed float of the Trinidad and Tobago dollar in April 1993. Non-agricultural goods have been removed from the negative list and subsidies to agriculture substantially reduced. Anti-dumping legislation has been passed but the regulations required to put the legislation into effect have not yet been produced. While the change in parity of the Trinidad and Tobago dollar has helped the agricultural sector, late

payment of subsidies and granting of licenses for importation of heavily subsidized agricultural products have severely damaged the agricultural sector. The question therefore is: will the sector survive competition from heavily subsidized imports, still allowable under the new GATT agreement, until such time as there is complete removal of subsidies in all countries, if this ever occurs?

THE ECONOMIC IMPACT OF MODERN BIOTECHNOLOGIES ON CARIBBEAN AGRICULTURAL DEVELOPMENT

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The application of modern biotechnologies could be critical in the development of a more sustainable, economically-viable and environmentally-friendly agriculture in the Caribbean. However, in order to have a positive impact, several factors need to be considered in the development of national and regional biotechnology policies and programs. These include: (1) the present trend in global economy viz. privatization, foreign investment cuts in public spending, NAFTA, GATT and the impact of these on the economics and policies of Caribbean countries in general and agriculture in particular, (2) the increasing poverty/hunger and widening of gap between the rich and the poor in third world economics, (3) a rapidly deteriorating rural economy which depends heavily on agriculture, (4) the need for inputs from a multidisciplinary team in elaborating such policies and programs, and (5) the notion that it is possible to catch up with the advanced countries by either importing their technology or imitating their approaches. These factors provide the basis for examining qualitatively, the impact of introducing certain selected biotechnologies on Caribbean agricultural economy.

MULTIPLICATION, DISTRIBUTION, AND QUALITY OF MAIZE SEED IN TRINIDAD

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In Trinidad, maize seeds are obtained from hybrids imported commercially from the United States and through local production of one open-pollinated variety (OPV) at the Ministry of Agriculture, Lands and Food Production Chaguaramas Agricultural Development Project (CADP). Agronomic varietal trials undertaken in 1992 and 1993 indicated that Across 7728, the OPV, multiplied by CADP, possessed reasonable genetic potential. However, multiple site field tests and indoor emergence tests indicated that seed quality of CADP material was inferior to popularly grown Pioneer hybrids and to all other seed multiplication institutions evaluated. Implications of poor seed quality at CADP are discussed in relation to Trinidad's official policy of diversification out of sugar cane as part of structural adjustment policies of the region.

AGRICULTURE AND THE ENVIRONMENT

SUSTAINABLE ORGANIC AGRICULTURE, RURAL DEVELOPMENT, FAIR TRADE AND INTERNATIONAL MARKET OPPORTUNITIES FOR THE CARIBBEAN

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Since the United Nations Conference on Environment and Development (UNCED) in Brazil, June 1992, much has been said about the environment, rural, social, economic development and agriculture and their respective roles in building a global sustainable future. These concerns are of particular interest to the small island countries of the Caribbean, their peoples and their fragile ecosystems. It is now believed by many experts that by employing the holistic principles of organic agriculture and by providing production and marketplace-based incentives, environmental degradation can be reversed and a more responsible social, economic and environmentally-friendly agriculture can bring great benefits to the region. Thereby, keeping rural people on the land, productive and economically stable. It will also help to further reverse ecosystem degradation, and start regeneration to help relieve deep poverty and remove the social and economic inequities that cause people to dislocate to urban centers, (already beyond their carrying-capacities) in search for jobs that are not available and do not serve their families and/or their rural communities. Sustainalble organic agriculture and its growing environmental and socially responsible marketplace can be one road to a more sustainable future for the Caribbean.

NUTRIENT ANALYSES/IMPLICATIONS OF SELECTED PLANTS WHICH ARE USED IN THE U.S. VIRGIN ISLANDS TO PREPARE BUSH TEAS AND/OR FOR MEDICINAL PURPOSES

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Scientific data indicates that selected plants which have been used for hundreds of years by U.S. Virgin Islanders for nourishment and/or medicinal purposes contain both nutritive and non-nutritive components which are biochemically active and in some cases are potent sources of specific nutrients. Of particular interest are those nutrients which have been classified as being antioxidants and anticancer. The nutrients in the bush/herbs should be viewed with the context that they: (a). Exert pharmacologic effects on the human body and affect the healing process and (b). Contribute positively to the health and well-being of the population.

CROPPING AND PRODUCTION SYSTEMS

NEW SYSTEMS FOR HYDROPONIC CULTURE OF PEANUT FOR BIOREGENERATIVE STUDIES

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Peanut (*Arachis hypogea L.*) is a high energy yielding crop identified for use in controlled ecological life support systems (CELSS) proposed for extra-terrestrial environments. Soilless culture of peanut can also become an economically viable cropping alternative for the Caribbean because it has the potential to maximize plant biomass production. Peanut research at Tuskegee University has utilized hydroponic growing systems in greenhouse experiments to evaluate the effect of channel size, pore size of screens, and grids on both foliar growth and gynophore and pod development. New Improved Spanish and Georgia Red peanut cultivars were used for these experiments. In the systems used at Tuskegee University, nut yield varied from 0.090 to 5.00kg/sq m. Effects of the Tuskegee University hydroponic systems on foliar growth and pod yield of peanut will be discussed.

PLANT BREEDING AND BIOTECHNOLOGY

ANATOMY OF TUBERIZING STEMS AND ROOTS IN CASSAVA (*MANIHOT ESCULENTA CRANTZ*)

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Cassava stem cuttings when planted in an inverted position produce subterranean lateral shoots, the bases of which enlarge and store up starch, thus, forming "stem tubers." The anatomical events occurring during the formation of these "stem tubers" are described and compared to those occurring during the formation of root-tubers. The significance of "stem tubers" for cassava production is discussed.

EFFECT OF EXPOSURE TO PLANT GROWTH REGULATORS ON CELLULAR DIFFERENTIATION

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Leaf disks (4.5 mm) from *Petunia hybrida* were grown on filter paper supports with Murashige and Skoog medium containing 30 g/l sucrose (Control) or 5 mg/l 6-benzylaminopurine (BA). At two-day intervals through the 20th day, 20 leaf disks were transferred to the control medium, 20 were weighed and analyzed for total protein and soluble carbohydrate content, and 6 were fixed for

histological studies. Plant cell division was first evident by day 4 and occurred 2-6 cells in from the cut surface. Soluble carbohydrate and protein contents of the leaf disks decreased after 4 days and 8 days, respectively. Organized meristematic zones of callus were observed by day 8 and meristems with a developing leaf primordium were evident by day 10. Shoots, emerging from the callus, were visible in the culture vessels by day 12. At least an 8-day exposure to BA was required for continued shoot development when transferred onto control medium, and an average of 0.5 shoots per leaf disk was obtained. The maximum number of shoots (8.7 average) occurred after 20 days exposure to BA. Extended exposure to BA beyond 20 days resulted in reduced callus and shoot production. Limiting the exposure time of petunia leaf disks to BA can be used to maximize adventitious shoot production.

CLONING OF PUTATIVE LECTIN GENES FROM TROPICAL LEGUMES USING PCR AND DEGENERATE PRIMERS TO THE *PHYE PHYTO* HEMAGGLUTININ GENE

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The recent development of the Polymerase Chain Reaction (PCR) technique has revolutionized as well as simplified many areas of genetics. PCR can be used in conjunction with traditional breeding techniques to quickly examine ingression of desirable traits into new genetic backgrounds. We are using PCR to search for novel lectins among Leguminous tropical plants (Subfamilies *Papilionoideae* and *Faboideae*). Lectins are a class of glycoproteins that specifically recognize and bind other glycoproteins. Traditionally, legumes have been a rich source of many different lectins. Using degenerate primers to the *Phaseolus* lectin phyE gene and PCR techniques we are surveying tropical legume species as a possible source for novel lectins. We have isolated and cloned PCR fragments of an appropriate size for lectin genes. Further characterization of the cloned fragments will determine the relatedness of the amplified sequences. It is hoped that the novel lectins isolated by this process can be of use as tools in the diagnosis of cancer.

FORAGE CROPS/LIVESTOCK SYSTEMS

PERENNIAL SUMMER LEGUME FEED FOR GOATS: GERMINATION OF MIMOSA SEEDS

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Mimosa (*Albizia julibrissin*) is a warm-season legume that can provide adequately high utility forage for small ruminants for the southeastern United States. However, the production and management of this plant have not been established. The objective of this research is to determine the effects of seed treatment on imbibition, germination, growth and development of mimosa. A series of studies were conducted under laboratory and greenhouse conditions, utilizing several scarification methods in completely randomized design experiments. Analysis shows that the highest rate of germination (94%) was obtained when seeds were heat treated (60°C to 90°C). The lowest rate of germination (4%) was obtained when seeds were soaked in water. The data further show that seeds previously treated with other forms of scarification

and did not germinate did so when exposed to heat treatment. It would appear that mimosa seeds after being heat treated will germinate readily even with prolonged storage at both cool (4°C) and room temperatures.

TROPICAL FRUITS & TREE CROPS

CHANGES IN PEROXIDASE ASSOCIATED WITH INFECTION OF COCOA STEMS BY *PHYTOPHTHORA*

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Qualitative and quantitative changes of enzymes in plants have been reported in relation to their resistance to fungal pathogens. In this study, the activities of peroxidase in cocoa stems of resistant and susceptible cultivars were investigated. Electrophoretic patterns of the enzyme were also studied. Peroxidase activities significantly increased in the stems of resistant plants while only very slight increase was observed in the susceptible ones. In terms of banding patterns, significant differences were observed in band-intensity of the resistant plants compared to those of susceptible plants. Some differences were observed in the banding patterns of infected cocoa stems in relation to the healthy ones. Since significant increase in peroxidase activities was observed only in resistant plants, this study suggests that post-infectional activities of peroxidase may be associated with plant defense reactions. Similar observations have been reported in several other host-pathogen interactions.

YIELD RESPONSE OF SOURSOP (*ANNONA MURICATA* L.) CULTIVAR 'BURRIS' TO TWO RATES OF NITROGEN, PHOSPHATE AND POTASH FERTILIZATION

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A fertilizer trial was conducted during June 1990-August 1993 to obtain an initial indication of the best fertilizer rates to apply to soursop. Nitrogen, phosphate and potash were each applied at 150 and 450g per plant. The best combination of fertilizers was that with the highest application rate of 450g per plant for each of nitrogen, phosphate and potash. Models of the response variables give the following predicted values for this combination as (a) total weight of marketable fruit - 73 kg; (b) total number of marketable fruit - 46; (c) percentage of the total weight of fruit that is marketable - 81%; (d) percentage of the total number of fruit that is marketable - 70%; (e) total weight of unmarketable fruit - 19 kg, and (f) total number of unmarketable fruit - 24.

POTENTIAL FOR PRODUCING POT CROPS IN THE U.S VIRGIN ISLANDS USING CHEMICAL GROWTH RETARDANTS

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This project funded by a three year CBAG grant looked at the possibility of adapting several commonly used landscape species for pot culture. Family groups targeted included Euphorbiaceae, Malvaceae, Rubiaceae, Solanaceae and Musaceae. Christmas Snowflake (*Euphorbia leucocephala* Lotsy.) was precisely scheduled for flowering in a 15-cm pot using Cycocel drenches at 3000 ppm. Five cultivars of Hibiscus were successfully dwarfed and kept in a floriferous state in 15-cm pots using Cycocel sprays of 2500 - 3000 ppm. Although spray applications of B9, Cycocel and Bonzi restricted growth and increased flowering in Pink Mussaenda, B9 at 2500 ppm appeared to produce the most attractive flowering plants. Plants were induced to flower twice in a single year. Bird Pepper (*Capsicum annuum* L. var. *aviculare*) was induced to bloom and fruit in 15-cm pots within 3-4 months from seed, using Sumagic. The most attractive and productive plants were obtained with Sumagic sprays at 4 or 6 mg/L following a single pinch. This technique elevated a common garden species into a potential dual-purpose crop - either for its ornamental or culinary values. In preliminary trials several other species including Allamanda, Calliandra, Yellow and Pink Shrimp plants and Achiote have been adapted for pot culture. It is hoped to extend this project to include the pot crop production of economically important cut flower species including Anthurium, Ginger Lily and Heliconia.

INTEGRATED PEST MANAGEMENT

REPORT OF *PASTEURIA PENETRANS* IN TRINIDAD AND TOBAGO AND PROPOSALS FOR RESEARCH ON ITS USE IN INTEGRATED CONTROL OF ROOT KNOT NEMATODES IN VEGETABLE CROPS

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A survey of 27 farms in 8 major vegetable-growing areas in Trinidad and Tobago revealed that *Meloidogyne incognita* was the only root-knot nematode species identified and that gall ratings of 2.3 to 8.3 (scale of 0-10) were recorded. Pasteuria penetrans was present in 26% of farms sampled. This is the first report of *P. penetrans* in Trinidad and Tobago. Five to 27% of juveniles from soil in 5 farms were encumbered with 1 to 9 spores of P. penetrans. When roots were incubated for 7 days, 5 to 65% of juveniles were found encumbered with spores in about 15% of the root samples. In pot studies, the vegetable cowpea selection, Los Banos bush Sitao 1, recorded a gall rating of 0 (scale of 0 to 10) compared to a gall rating of 7 for tomato (*Lycopersicon esculentum* L.) (var. Capitan), when they were inoculated with 1,000 juveniles of *M. incognita*. The utilization of *P. penetrans* in an integrated approach, involving crop rotation, resistant varieties and other cultural practices for the control of root knot nematodes in vegetable crops is discussed.

EFFECTS OF TWO PLANT GROWTH REGULATORS ON GROWTH AND YIELD OF CHIVE (*ALLIUM FISTULOSUM* L.)

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A container experiment was conducted to determine the effects of two plant growth regulators, gibberellic acid 3 (GA_3) and the cytokinin, N-phenylmethyl -1H-purine 6-amine (PMPA), on the growth and yield of "Criollo Rojo" chive (*Allium fistulosum* L.). Both regulators were applied by bulb immersion during 24 hours just before planting, using 0,1, 10, 100 and 1000 ppm solutions of both regulators. There was no significant effect of the regulators on the number of days from planting to plant emergence. Bulb dry and fresh weight were significantly higher in plants treated with 10 and 100 ppm of GA_3 and 10 ppm of PMPA, as compared to the other treatments tested. Dry weight accumulation in the leaves and plant height were significantly higher at 10 and 100 ppm of Ga_3 According to these findings, immersion treatment with these regulators resulted in significant growth and yield improvement at 10 ppm PMPA and 10-100 ppm GA_3. Lower or higher rates were not effective.

INTRODUCTION

In the Dominican Republic, chive (*Allium fistulosum* L.) is a minor vegetable crop in terms of the area under production. However, the country ranks among the world leaders in per capita consumption of this seasoning vegetable. Very little research has been carried out worldwide to determine the effects of plant growth regulators on chive, and the Dominican Republic is not an exception in that matter. Due to lack of high level technology in chive production, yield of this crop is much lower than its apparent potential, and for that reason a series of research works have been conducted with the objective of increasing the productivity of chive.

The specific objectives of the experiments presented in this paper were to determine the effects of gibberellic acid 3 (GA_3) and the cytokinin phenylmethyl purine amine (PMPA) on foliar and bulb growth (yield).

MATERIALS AND METHODS

The experiments were conducted in Santo Domingo, Dominican Republic, using the native variety "Criollo Rojo" of chive (*Allium fistulosum* L.). A completely randomized design with five replications was used. The treatments consisted of 24 hour immersion of the seed-bulbs in 0, 1, 10, 100 and 1000 parts per million (ppm) solutions of the plant regulators one day prior to planting. Bulbs were planted on a sandy loam soil in plastic containers 15 cm in diameter and 15 cm of height. Plant nutrition and protection was the same for all treatments, following the recommendations for this crop. At harvest, the variables plant height, bulb fresh weight and bulb dry matter weight were measured.

RESULTS AND DISCUSSION

Plant height was significantly higher at rates 10 ppm PMPA and 100 ppm GA3. Height significantly decreased at the remaining rates, with the shortest plants at 1000 ppm PMPA and the control treatments, indicating that maximum response is achieved within the range of rates tested in the experiment, where the low levels (1 ppm of PMPA and 1 to 10 ppm GA_3) do not stimulate growth in a significant way, whereas high rates (100 and 1000 ppm of PMPA and 1000 ppm GA_3) are excessive and limit the plant response. Plant height is considered an important feature in chives, since the leaves are also used as seasoning when the produce is consumed fresh, and abundant foliar growth is usually related to large-sized bulbs.

The main component in chive yield is bulb fresh weight. The highest values for this variable were found in plants receiving 10 ppm of PMPA or 10-100 ppm of GA_3. These were significantly higher than the control, which was not significantly different than the other treatments. Both 100 ppm of GA_3 and 10 ppm of PMPA also resulted in taller plants, indicating that at those rates there seems to be an overall promotion of growth. Bulb dry weight is an important variable, because it has been demonstrated that bulbs having a higher content of dry matter tend to keep better and for a longer time in storage. The treatments of 10 and 100 ppm of GA_3, and 10 ppm of PMPA resulted in the highest content of bulb dry matter, being significantly different than the other treatments. The lowest dry matter values corresponded to the 1000 ppm PMPA treatment, which was significantly lower than all the treatments tested. Again, 10 ppm PMPA and 100 ppm GA_3 resulted significantly superior. The increase in bulb weight (both fresh and dry) might be due to an effect of both regulators on the size and or division of cells in the seed-bulb after treatment.

CONCLUSIONS

Treatment of the seed-bulbs of "Criollo Rojo" chive (*Allium fistulosum* L.) with 10 ppm of PMPA or 100 ppm of GA_3 resulted in significant increase of the three variables studied, namely, plant height and bulb fresh and dry weight. Rates below or above these resulted in suboptimal growth, although some rates were significantly better than the control. According to the results of these experiments, seed-bulb treatment with either 10 ppm PMPA or 100 ppm GA_3 can significantly improve the yield of "Criollo Rojo" chive.

EFFECTS OF GIBBERELLIC ACID (GA_3) ON GROWTH AND YIELD OF LEEK (*ALLIUM PORRUM* L.)

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An experiment was conducted to determine the effects of gibberellic acid (GA_3) on growth and yield of "American Flag" leek (*Allium porrum* L.) grown in containers. It was found that GA_3 foliar application in dosages ranging from 0 (control) to 50 ppm did not cause significant effects on growth or yield when applied seven days after transplant (four-leaf stage). However, GA_3 application 21 days after transplanting (seven-leaf stage) significantly increased leaf area as well as pseudo-stem weight and diameter at rates 30, 40 and 50 ppm, although no significant effects were detected on plant height and pseudo-stem length. These results suggest that yield and quality of "American Flag" leek can be enhanced by GA_3 application in the seven-leaf stage.

INTRODUCTION

In the Dominican Republic, leek (*Allium porrum* L.) is a crop grown in small areas and of a limited market. The general public prefers the use of other Allium species such as garlic, chive and onion, although leek is also appreciated among consumers of higher incomes. The main markets for leek are the the exportation market as well as the hotel market, which demands leek for special dishes for the tourists. The supply of good quality leek is limited, because leek grows better in cool climates, but growers in the cool regions of the country prefer to produce more profitable crops such as garlic. Leek growers in low altitude-warm climate conditions usually produce leeks that are too thin for the consumer's requirements. Plant growth regulators can alter the size of plant organs, and the several experiments to determine their effects on leek growth were included in our program of experiments on plant growth regulators in Allium crops in the Dominican Republic. The objective of the experiments decribed in this paper were to determine the possible effects of foliar applications of GA_3 and PMPA on "American Flag" leek, as well as to determine the difference in effect when the regulators were applied during the four-leaf stage and the seven-leaf stage.

MATERIALS AND METHODS

The experiment was conducted in Santo Domingo, during the summer (June-September) of 1993. A completely randomized design with six replications was used. Plantlets were grown in a nursery and transplanted to sandy loam soil in plastic containers 15 cm height x 15 cm diameter. Transplanting was done when plants reached the four-leaf stage. Treatments consisted of foliar sprayings of aqueous solutions of GA_3 at rates of 0, 10, 20, 30, 40 and 50 parts per million (ppm), at either the four-leaf stage or the seven-leaf stage. The variables evaluated were leaf area, plant height and pseudo-stem weight, diameter and length, which were determined at harvest time, 50 days after transplanting.

RESULTS AND DISCUSSION

No significant effect of the treatment was found for the variables plant height and pseudo-stem length at either application time. Leaf area (data not shown) and pseudo-stem fresh

weight and diameter were significantly higher at rates 30, 40 and 50 ppm when applied 21 days after transplanting (seven-leaf stage). The lower rates (10 and 20 ppm) were not significantly different than the control. No significant effect of the regulator was found when the application was performed during the four-leaf stage, regardless of the rate. It is possible that at the four-leaf stage this cultivar of leek is not sensitive to GA_3 application. It is also possible that the application seven days after transplanting might be too soon for the plant to react to treatment, because it might not be recovered from the stress of transplant. The significant increases in pseudo-stem diameter and weight are probably due to a GA_3 stimulation of cell division and/or growth of the leaf sheaths of which the pseudo-stem consists. According to the results, rates of 30 or more ppm are needed to significantly stimulate this response.

CONCLUSIONS

Leek plant did not show significant responses to GA_3 at any of the rates tested when treated during the four-leaf stage. Significant responses were found for leaf-area, pseudo-stem diameter and pseudo-stem weight at rates 30-50 ppm applied at the seven-leaf stage. Since pseudo-stem thickness (diameter) is a major component of the quality requirements for marketing, it is suggested that GA_3 application at rates 30-50 ppm during the seven-leaf stage might result in better quality leeks. Other experiments testing different rates and application times have been included in our research schedule to explore other possible response patterns.

GROWTH AND FLOWERING RESPONSES OF CULANTRO (*ERYNGIUM FOETIDUM* L.) TO PROGIBB SPRAYS

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Culantro also known as shadow beni, chadron beni, fit weed, bandhaniya and recao in the Caribbean is an aromatic biennial herb native of Central America and the West Indies where it is used as a major ingredient of many West Indian and Latin American dishes. Although closely related to the Asian culinary herb - cilantro or coriander, culantro is mainly prized for its green serrate spatulate-shaped leaves the main source of its oil. Like many other umbelliferae under tropical conditions culantro produces large seed-bearing inflorescences which are labor-intensive to remove, retard leaf growth and hence decrease the market value of the plant. This study incorporated the growth-promoting hormone ProGibb as sprays from 50 to 200 ppm to 1-month old culantro plants grown under 53% shade. Preliminary results indicated increased leaf length and size and reduced flower-size to increasing levels of ProGibb. Maximum leaf length, leaf dry weight and minimum flower growth were recorded at Progibb concentrations of 100 ppm and above. Treated plants also appeared to produce more vegetative side shoots. Postharvest observations indicated no apparent decrease in shelf life nor loss of characteristic leaf aroma in leaves harvested from ProGibb-treated plants. Inflorescences from sprayed plants were less thorny and woody, reduced in size, had leaf-like appearance and produced characteristic culantro aroma indicating that they may also be utilized in culantro cuisines.

THE MINOR TROPICAL AND SUB-TROPICAL FRUIT PROJECT ON ST. CROIX

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Traditionally, fruits research on St. Croix has centered around the major tropical fruits (banana, avocado, mango, papaya and citrus). While a variety of minor fruits have been introduced into St. Croix over the years, no systematic effort has been made to document their growth and production. Less-traditional tropical fruits, like sapodilla, golden apple, the annonas, are excellent alternatives to traditional fruit crops in the Caribbean basin. Small-scale production of minor fruits and nuts could increase the variety and availability of fruits to the local market. Additionally, specialty markets for minor fruits are growing on the U.S. mainland. The University of the Virgin Islands Agricultural Experiment Station has initiated a long term project to evaluate a wide variety of tropical and sub-tropical fruits and nuts with the goal of diversifying fruit production on St. Croix. The objectives of this project are to assess the adaptability of selected minor tropical and sub-tropical fruits and nuts to St. Croix conditions, evaluate their production potential and develop guidelines for the suitablilty of minor fruits and nuts by soil association and rainfall regime on St. Croix.

INTRODUCTION

Fruits research on St. Croix has focused primarily on the major tropical fruits (banana, avocado, mango, and citrus). While a variety of minor tropical fruits have been introduced into St. Croix over the years, no systematic effort has been made to document their growth and production. The University of the Virgin Islands Agricultural Experiment Station has initiated a long-term project to evaluate a wide variety of tropical and sub-tropical fruits and nuts with the goal of diversifying fruit production on St. Croix.

JUSTIFICATION

There is a need for diversification in fruit and nut production on St. Croix. The high cost of land and labor, low rainfall and scarce water resources, and shallow, calcareous soils have made it difficult to compete with large foreign producers of the major tropical fruits. Less-traditional tropical fruits are excellent alternatives to these crops in the Caribbean Basin. Small-scale production of minor fruits and nuts could provide a niche for local producers. Markets, such as roadside stands, fruit drink vendors, producers of candies, jellies and ice creams, and tourist hotels are available or could be developed. Additionally, specialty markets for minor fruits are growing on the U.S. mainland. The introduction of minor fruits and nuts could increase the variety and availability of fruits in the local market. As Virgin Island society shifts from its traditional agricultural base to a tourism and industrial economy, agricultural lands are being divided into smaller plots for housing. Introduction of new varieties of small fruits and nuts could permit development of home gardens and backyard fruit orchards which would benefit the local populace both economically and nutritionally.

OBJECTIVES

1. Assess the adaptability of minor tropical fruits and nuts to climatic and soil conditions on St. Croix.
2. Evaluate the production potential of selected fruits and nuts on St. Croix.

3. Develop guidelines for the management of selected minor fruits and nuts by soil association and rainfall regime.
4. Establish a germplasm collection of minor fruits and nuts at the University of the Virgin Islands Agricultural Experiment Station.

METHODOLOGY

Four sites have been selected that reflect the differences in soil and rainfall found on St. Croix. The initial phase will entail a broad screening of a wide variety of minor fruits species at each of the four sites. Three plants of each species will be planted at each site. Survival, growth, flowering and fruiting data will be taken. At the end of this phase, fruits will be selected as the most appropriate for each area of the island. In the second phase, studies will be conducted using various fertilizer and irrigation regimes in order to develop guidelines for appropriate management practices for the each of the selected minor fruits.

FIELD PERFORMANCE OF SEVEN TISSUE CULTURE-PROPAGATED WHITE COCOYAM (*XANTHOSOMA SAGITTIFOLIUM* L. SCHOTT) GENOTYPES IN COSTA RICA

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A study on field performance of seven in vitro-propagated genotypes of white cocoyam (*Xanthosoma sagittifolium* L. Schott) (Amarilla Especial, Amarilla Trinidad, Blanca, Blanca Venegas, Macal Sport, Viequera and a local cultivar) was done. The results showed that the number of leaves, plant height and photosynthetic area during plant growth were similar between five genotypes (Amarilla Trinidad, Blanca, Blanca Venegas, Viequera and Macal Sport) and the local cultivar. Yield evaluation was done 444 days after planting. Viequera and Macal Sport showed the highest cormel production per plant (3.55 and 3.45 kg respectively), while the local cultivar had the lowest (1.84 kg). In addition to the yield, Macal Sport had the highest percentage of marketable cormels (35.35), while the local cultivar had the lowest (3.3%). These results indicate that Viequera and Macal Sport genotypes had an excellent performance to the evaluated area and may be introduced to Costa Rican growers.

RAPD MARKERS FOR MAJOR GENES OF DISEASE RESISTANCE QTLs IN RILs OF THE COMMON BEAN (*PHASEOLUS VULGARIS* L.)

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Seventy-nine recombinant inbred lines (RIL's) were screened for resistance to common bacterial blight (CBB) in leaves and bean golden mosaic virus (BGMV). Resistance to these diseases showed a normal distribution. Individuals at the extremes of the distribution were bulked for each disease and screened with decamer primers of random sequence. Putative linkages between RAPD markers and QTLs with major effects were obtained by regression analyses using SAS and the LOD score method using MAPMAKER.

IDENTIFICATION OF COCOYAM CULTIVARS (*XANTHOSOMA SAGITTIFOLIUM* L. SCHOTT) FROM IN VITRO CULTURE USING ESTERASE ISOENZYME ANALYSIS

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Species of *Xanthosoma* and other members of Araceae family are important food staples in the tropics. There are many cultivars of each of the edible aroids and their names vary from region to region Despite their significance, no breeding and little systematic selection has been undertaken with these crops. Isoenzyme analysis of leaf tissue was used to characterize four cocoyam cultivars (Local, Japónica, Amarilla Trinidad and Macal Sport) propagated by *in vitro* culture in order to establish a genotype identification system. The leaf esterase isoenzymes were studied using polyacrylamide gel electrophoresis and alpha and beta naphthylacetate mix as substrates. Three zones of enzyme activity were identified. As many as nine activity bands were resolved on individual gels. The results indicate that esterase isoenzyme system is sufficiently sensitive to detect differences between the four cultivars of *X. sagittifolium* where are often difficult to distinguish by morphological characteristics alone.

EFFECT OF THREE CUTTING INTERVALS ON SIX *PENNISETUMS* AT TWO LOCATIONS IN PUERTO RICO

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Dwarf napiergrass (*Pennisetum purpureum* Schumack) selections N75, N114, N127, N128, and tall cultivars, Merker (M) and Merkeron (N43) were evaluated at 45-, 65- and 85-day cutting intervals (CI) on an Oxisol and Ultisol during a two-year period. N43 was superior to the remaining grasses in terms of dry forage yield (DFY) and crude protein yield (CPY) with 7.9 and 0.60 t/ha, respectively. Among the dwarf selections, N128 had the highest DFY (6.0 t/ha), while N75 and N127 had the highest crude protein content (CPC) with 9.6 and 9.9% respectively. The optimum harvest time for all the grasses was 65 days, when the best compromise could be reached for DFY, CPC and *in vitro* dry matter digestibility (IVDMD). At that stage, the dwarf selections produced an average of 5.6 t/ha of excellent forage having an 8.1% CPC and 55% IVDMD. The dwarf selections have potential for use under grazing management due to their high leaf/stem ratio than the tall cultivars although their DFY was significantly lower in this study.

SOLVING THE *HELICONIA* GERMINATION PROBLEM

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Seeds of *Heliconia* spp. do not germinate readily. In order to develop new cultivars of *Heliconia*, rapid and reliable germination is highly desirable. Results from experiments with *H. psittacorum* and *H. birdiana* seeds are described in which time to germinate has been decreased and percentage germination has been enhanced. Photos of "Dame Nita" and "Sir Gary", two new promising varieties of *H. psittacorum* selected from our seedling and exhibited at the 1993 Chelsea flower show, will be displayed.

BIOLOGICAL NITROGEN FIXATION AFTER STEM CUTTING IN TUBEROUS *PACHYRHIZUS EROSUS*

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INTRODUCTION

Yam bean (*Pachyrhizus erosus*) a tuber-forming legume, is particularly suitable for evaluating the potential availability of the plant reserve carbohydrates for nitrogen fixation (Vaillant et al., 1990, 1993). The tuber of this species contains soluble sugars and starch which account, respectively, for 32 and 15% of dry weight. Furthermore, tuberous and non-tuberous plants may be available in inductive or noninductive environment (Robin et al., 1990; Sorensen et al., 1993).

A stem cutting experiment was conducted with tuberous *Pachyrhizus erosus* in order to evaluate its potential for maintaining N fixation after aphotosynthate stress. This paper report the effects of such a treatment on the Acetylene Reduction Assay (ARA) of nodules and on the concentration of N fixation products in underground organs.

MATERIALS AND METHODS

Pachyrhizus erosus seeds were sown in December 1992 at INRA Guadeloupe. After 10 weeks of growth, detopping was carried out by cutting the stem at 2 cm above the tuber. The underground part was maintained in soil and watered every three days to prevent sickness. The rate of N fixation was estimated by the ARA and expressed as umol ethylene h^{-1} g^{-1} fresh weight of nodules. Amino compounds and ureides were extracted in 80%(v/v) ethanol. The ethanol soluble extracts were vacuum dried and redissolved in water. Amino compounds were assayed by the ninhydrin method. Ureides were assayed according to Trijbel and Vogels (1966). Total nitrogen was assayed by the Kjeldahl procedure.

RESULTS

Detopping resulted in a 70% decrease of N fixation, which then remained stable for 17 days. Total nitrogen in underground parts increased by 52% after 14 days. In nodules, ureides and amino compounds increased until 2 days and then dropped to about the same level as that of the control. Both ureides and amino compounds remain stable in roots. In the tuber, ureides increased by 10 after 11 days whereas amino compounds were unchanged.

CONCLUSIONS

Tuber plays an important role in sustaining nitrogen fixation after detopping. In the presence of tuber, N fixation is maintained at 30% of the control after stem cutting. We showed a transient accumulation of nitrogen fixation products (ureides and amino compounds) in nodules and then a translocation and accumulation in tubers. As a result, tuber accumulated N fixation products which were then utilized for heterotrophic regrowing.

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ADVANCED TECHNOLOGY FOR AGRICULTURAL RESOURCE MANAGEMENT

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Available advanced technology could ease the decision making process for agricultural resources. Although the technology is currently available, its arrangement in a concise and integrated manner dedicated to agricultural applications requires much effort and validation. The Agricultural and Environmental Geographic Information Systems (AEGIS) is one of such technological tools lacking validation.This paper discusses the use of advanced technological tools in the development of a methodology to aid the decision making process of planners and administrators of land and water resources. The tools used in this project are crop simulation models (DSSAT), soil erosion models (RUSLE, WEPP), a chemical transport model (GLEAMS, CREAMS), a relational data base management system (DBASE IV) and a geographic information system (PC-ARC/INFO).

AGRICULTURE IN UNION WITH THE ENVIRONMENT - THE BOTTOM LINE FOR AGRICULTURAL DEVELOPMENT

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Nonpoint source (NPS) pollution is the largest remaining water quality problem in the US and the Caribbean and Agriculture is considered to be one of the largest contributors to NPS pollution; these regions attribute forty one percent (41%) of their problem to agriculture. Data from the US indicate that approximately one-third of agricultural NPS pollution is caused by runoff from feedlots, pasture lands and other fertilized farming areas. The present concern regarding agriculture and the environment is that we seem to be approaching the union of the two with much hesitation and apprehension. Both agricultural scientists and ecologists have agreed that the marriage between farming and ecology can be successful through proper management. Of course the burden is not entirely on agriculture to "make it work", but on all of us as consumers and users of the environment and what it has to offer, but more importantly on the NPS program, which is an integral part int he planning of a workable Agricultural Development Strategy.

SOIL DIVERSITY IN PUERTO RICO

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Based on the most recent data available, 172 soil series have been identified in Puerto Rico. They are grouped in nine of the eleven soil orders recognized in *soil Taxonomy:* Alfisols, Entisols, Histosols, Inceptisols, Mollisols, Oxisols, Spodosols, Ultisols, and Vertisols. Absent from the pedologic scene of the Island are Andisols mainly because there is no recent volcanic material. Aridisols are lacking because the aridic soil moisture regime has not been officially recognized. Further studies, however, may reveal the presence of an aridic soil moisture regime in the southern region particularly in the Santa Isabel area and in the southwest near Cabo Rojo. If so, the occurrence of Aridisols will be confirmed. As the island has an area of less than 9,000 km^2, the diversity of soils is extraordinary. It can be attributed to the contrasting ecosystem variability over short distances and to the environmental factors that control soil forming processes climate, biology, geology, and geomorphology. The classes of Soil Taxonomy provide for an expression of this diversity. Appreciation of soil diversity and aligning management technology to match the specific soil requirements results in increased productivity of agricultural systems.

SENSORY TEXTURE PROFILE ANALYSIS (TPA)OF DEEP-FRIED BANANA CHIPS

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A sensory texture profile for banana chips prepared using different pre-frying treatments was developed utilizing Goya Plantain Chips as the standard. The pre-frying blanching treatments used were a zero blanch as the control, 2 min. at 70°C, 5 min. at 50°C; and 30 min. at 70 and 100°C. The texture profile was determined by an experienced panel, trained at the Experiment Station specifically for TPA measurements. The chips were described generally as highly fracturable, flaky, dry and somewhat oily. There was no viscous, adhesive or gumminess characteristics in the initial and masticatory sequences. The breakdown tended to be formation of sharp jagged slivers that absorbed saliva at a slow rate and then changed into a grainy paste with substantial residue on the gums and teth after swallowing. Differences in textural characteristics were observed mainly in the 30 min. blach samples, particularly during the masticatory and residual sensations. The unblanched, 2 min. and 5 min. samples were comparable in texture.

SUPPRESSION OF *SCLEROTIUM ROLFSII* AND *PYTHIUM APHANIDERMATUM* BY COMPOSTS OF SUGAR CANE FACTORY RESIDUES

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Compost of mixtures of bagasse, filter mud and vinasses were investigated for their suppresiveness to the soil-borne plant pathogenic fungi *Sclerotium rolfsii* and *Pythium aphanidermatum*. Germination of sclerotia of *S. rolfsii* was reduced when they were incubated in the composts. Disease incidence of *P. aphanidermatum* and of *S. rolfsii*, respectively on cucumber (*cucumis sativus*) and lentil (*Lens esculenta*) seedlings grown on the inoculated compost, decreased also, comparatively to the uninoculated compost. Suppression or *S. rolfsii* by the compost is of both chemical and biological nature (involvement of toxic compounds in the filter mud and of the antagonistic fungi *Gliocladium* and *Trichoderma*). Suppression of *P. aphanidermatum* seems to be related to the competitive effects of different fungi, *Aspergillus sp.*, *Geotrichum sp.* and an apparentlly non-sporulating *Pythtum* species.

DETRIMENTAL EFFECTS OF REPEATED CYTOKININ APPLICATION ON "RED CREOLE" ONION (*ALLIUM CEPA* L.)

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An experiment was conducted to determine the effects of repeated application of a cytokinin, N-(Phenylmethyl) -1H-purine 6 amine, on the growth and yield of "Red Creole" onion (*Allium cepa* L.). Results showed detrimental effects of the cytokinin as the application frequency was increased. No significant difference was found between control plants and those sprayed with the cytokinin at rates 100 or 200 ppm 15 days after transplant, but in these treatments growth and yield were significantly higher than in plants sprayed every 15 days after transplanting. Treatments every 7 days after transplanting gave results significantly lower than the other frequencies. These results show that the application of this cytokinin to "Red Creole" onion at rates 100 or 200 ppm did not promote growth or yield, and that repeated treatment actually decreased overall growth and yield.

INTRODUCTION

There is abundant literature reporting the effects of many plant growth regulators on different crops, but little information is available about the practical applications of these substances on onions and their effects on the growth and yield of this crop. Research has been concentrated mostly on the aspects of using anti-sprouting products during storage.

Undocumented claims made by onion growers that different hormonelike substances actually increase yield and/or produce quality has created the need to verify these claims. In order to do that, a series of experiment have been and will be carried out. The present paper is an advance of the findings on the effects of the application of a cytokinin (PMPA) to red onion. The main objective of this experiments was to determine the effect of repeated spraying of PMPA on the fresh weight, dry weight and diameter of the bulbs of "Red Creole" onions.

MATERIALS AND METHODS

The experiment was conducted in Santo Domingo, located at sea-level. A completely randomized design with six repetitions was used. The experiment was done twice, obtaining very similar results. Treatments consisted of spraying of the plant growth regulator PMPA, at rates 0, 100 or 200 parts per million (ppm) in water solutions. PMPA was applied to the leaves at three different frequencies: (a) only once 15 days after transplanting (DAT), (b) every 15 days, from 15 DAT to 15 days prior to harvest, (c) every 7 days, from 15 DAT to 15 days prior to harvest.

"Red Creole", the main onion cultivar in the Dominican Republic, was used. Plants were transplanted 30 days after emergence, on plastic containers 15 cm of diameter x 15 cm height with sandy loam soil. Plant nutrition and protection was the same for all treatments, following the technical recommendations for this crop, Plants were harvested 120 DAT. At harvest, the variables bulb fresh and dry weight and bulb diameter were measured.

RESULTS AND DISCUSSION

The highest yield (bulb fresh weight), bulb dry weight and bulb diameter were found in the control and the treatments of 100 or 200 ppm 15 DAT. There was no significant effect due to rates, but frequencies had significant effects on the three variables.

Spraying every 15 days at either rate had a negative effect on all variables, yielding smaller bulbs

with a lower content of dry matter than plants without PMPA treatment or receiving the application just once. The negative effect was even greater when the frequency of application was every 7 days, resulting in bulb diameter and weights significantly lower than in the less frequent spraying. The responses of bulb fresh and dry weight as well as of bulb diameter to the rates and frequencies were consistent, clearly showing that at these rates, this product does not have positive responses in terms of the variables studied when it is applied at these rates on "Red Creole" onion.

CONCLUSIONS

The highest yield, dry matter accumulation and bulb diameter were found in the control and when PMPA was applied only once. No significant difference was found between the rates, but higher frequencies of application decreased the value of all three variables. According to these results, PMPA should not be expected to produce any significant increases in yield and/or bulb size in "Red Creole" onion, at least not when using the rates, frequencies and times of application used in these experiments. Further experiments are being performed, including other cultivars, rates, plant regulators, frequencies and times of application.

EFFECTS OF TWO PLANT GROWTH REGULATORS ON THE EARLY GROWTH OF GARLIC (*ALLIUM SATIVUM* L.) PLANTS

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ABSTRACT

In a replicated container experiment, gibberellic acid 3 (GA_3) and the cytokinin, N-Phenylmethyl-1H-purine, 6-amine (PMPA) were evaluated for their influence on early growth and dry matter accumulation in "La Flor" garlic grown at sea level during the summer season (June-August) in the Dominican Republic. Cloves were treated with either regulator at rates up to 200 ppm and evaluated seven weeks after treatment. The main finding was a significant change in the dry weight accumulated in the bulb at high rates of both regulators, associated with a significant reduction in leaf dry weight at the same rates.

INTRODUCTION

In the Dominican Republic, garlic is a very profitable crop. It is grown in the high altitude valleys of the country because of its climatic requirements of cool temperatures for bulbification. Attempts to grow garlic in the low altitude areas have resulted in low quality and yield, because plants produce abundant foliage but fail to develop bulbs of commercial size. Plant growth regulators can change the pattern of dry matter partitioning in crops, and such approach could be useful in "forcing" the plant to produce larger bulbs under unfavorable climatic conditions.

The objective of this research was to determine the possible effects of gibberellic acid (GA_3) and the cytokinin, N-phenylmethyl-1H-purine, 6-amine (PMPA) on the growth of "La Flor" garlic during its early stages, as an exploratory work for future research.

MATERIALS AND METHODS

The experiment was conducted in Santo Domingo, located at sea level, during the period of June to August 1993. Temperatures averaged 29.56 °C during the experiment. A completely randomized design with four to six replications was used. Garlic cloves were treated with GA_3 or PMPA by immersion for 24 hours in aqueous solutions of either regulator at rates 0, 10, 50, 100, 150 and 200 parts per million (ppm). After treatment, the cloves were individually planted in a sandy loam soil, in plastic containers of 15 cm diameter and 15 cm height. Plant nutrition and protection was provided according to the recommendations for this crop. Plants were harvested seven weeks after emergence. The variables evaluated were plant height, number of leaves, pseudostem diameter, total plant dry weight, bulb dry weight, pseudostem dry weight and leaf dry weight.

RESULTS AND DISCUSSION

No significant difference was found for the variables number of leaves, pseudo-stem dry weight and pseudo-stem diameter. Plant height was significantly higher in all the treated plants than in the control plants. Plants receiving 100 ppm GA_3 or 200 ppm PMPA were significantly taller than those receiving other rates. This promotion of growth might be expected for GA_3 treatment, since GAs work primarily on the elongation of stem and pseudostem tissue. For PMPA this result was similar to the responses found in other Allium crops like chive and leek in unpublished works of Morales-Payán. The possible mechanism of plant height promotion by PMPA is not certain, but it is likely that it is related to stimulation of cell division in the early stages of plant growth. Bulb dry weight is closely related to yield. High yielding plants tend to accumulate higher amounts of dry matter in the bulb during their early stages of development. The highest values for bulb dry matter accumulation were found in plants treated with 200 ppm of GA_3, being significantly different than the results of the other rates tested. Control plants were not statistically different than the other treatments, except 200 ppm GA_3 and 10 ppm PMPA, which gave the highest and the lowest bulb dry weight, respectively.

Since no significant difference was found for total plant dry weight (data not shown), a higher accumulation of dry matter in the bulb indicates that there has been a shift in dry matter partitioning favoring bulb over leaves. In fact, foliar dry weight was significantly lower at high rates of both regulators, which gave the highest results for bulb dry weight. The reason for such change in dry weight partitioning is not clear for GA_3, since this regulator tends to promote stem growth but not the growth of storage organs. However, the results were practically the same both times the experiment was conducted. For the cytokinin PMPA the results are more in agreement with the reports that cytokinins are involved in the development of storage organs such as tubers and bulbs.

CONCLUSIONS

Both plant growth regulators had significant effects on plant height, all treatments resulting in taller plants than the control. High rates of GA_3 and PMPA (150 and 200 ppm) were related to significant differences in dry matter accumulation, which increased in the bulb and decreased in the leaves, as compared to control plants and those treated with lower rates of both regulators. These findings might lead to important appications for the production of garlic under climatic conditions unfavorable to the crop, if the response is similar on field grown garlic. There is also the possibility that these treatments might also improve yield under favorable climatic conditions. Such possibilities will be explored in future experiments.

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