UWI
ST. AUGUSTINE CAMPUS

The Centennial Legacy Celebration of Agriculture
AT THE UWI STA

TROPICAL AGRICULTURE

Volume 98, No. 3
July 2021

100

THE JOURNAL OF THE FACULTY OF FOOD AND AGRICULTURE
THE UNIVERSITY OF THE WEST INDIES

(Formerly the Imperial College of Tropical Agriculture)

Established 1924

SPECIAL ISSUE IN COMMEMORATION OF 100 YEARS OF AGRICULTURAL LEGACY THROUGH TEACHING, RESEARCH AND INNOVATION

TROPICAL AGRICULTURE

The Journal of the Faculty of Food and Agriculture (Formerly Imperial College of Tropical Agriculture)
The University of the West Indies

Tropical Agriculture: is the quarterly Journal of the Faculty of Food and Agriculture (Imperial College of Tropical Agriculture) and is published in January, April, July and October of each year.

Editorial Offices: Tropical Agriculture, Communications and Publications Unit, Faculty of Food and Agriculture, The UWI, St. Augustine, Trinidad, Telephone (868) 662–2002 Ext. 82210, 82088

E–mail: tropical.agri@sta.uwi.edu

Website: https://sta.uwi.edu/tropicalagriculture.

Tropical Agriculture is published by the Faculty of Food and Agriculture.

General managing and publishing responsibilities

Ms Sarojini Ragbir

Subscription enquiries and orders: Tropical Agriculture, Communications and Publications Unit, Faculty of Food and Agriculture, The UWI, St. Augustine, Trinidad

Back Issues could be purchased online via http://journals.sta.uwi.edu/ta/.

Communications: All communication should be sent to Tropical Agriculture, Communications and Publications Unit, Faculty of Food and Agriculture, The UWI, St. Augustine, Trinidad.

Reprints: Minimum order 50, available from the publisher.

ISSN 0041–3216 (c) Tropical Agriculture (Trinidad).

Copyediting and typesetting: Communications and Publications Unit, Faculty of Food and Agriculture, The University of the West Indies, St. Augustine.

Printers: Communications and Publications Unit, Faculty of Food and Agriculture, The University of the West Indies, St. Augustine.

Table of Contents

Table of Contents (continued)

To: Corresponding Authors, Subscribers and Agents

Tropical Agriculture has developed arrangements with agricultural societies to publish papers of internationally acceptable quality in TA issues subsequent to their meetings. Agricultural research societies in the Caribbean and elsewhere that wish to have a similar arrangement with TA are invited to so indicate in a letter to the Editor in Chief.

We thank you for choosing TA to publish your work and look forward to subscription to the journal by your society.

Yours sincerely

Frank Bruce Lauckner

Editor In Chief

TROPICAL AGRICULTURE is pleased to receive and consider for publication, manuscripts of research papers, research notes* or reviews, in English on topics concerning tropical agriculture. The disciplines covered by the journal include: Soils, Environmental and Agro–Ecology; Crops; Livestock; Food Science; Agricultural Economics and Agribusiness; Food and Nutrition; Post–Harvest Technology; Geography; and Extension.

*The research note is not a full academic paper; it serves to advance a new idea, theoretical perspective, or methodological approach in a scientific study.

Foreword

One hundred years ago on 30 August 1921, the West Indies Agricultural College (WIAC) was formally established at St Augustine, Trinidad and Tobago. In 1924 WIAC was renamed as the Imperial College of Tropical Agriculture (ICTA) and in 1960 ICTA became part of the Faculty of Agriculture at the newly formed St Augustine campus of the University College of the West Indies. This faculty is now known as the Faculty of Food and Agriculture at The University of the West Indies (UWI).

The faculty is organizing a number of activities to celebrate this centenary including this special issue of Tropical Agriculture. Tropical Agriculture (TA) was first published in 1924 and this issue contains republications of 20 of the papers published since the first issue.

With nearly 5,000 articles published in TA over the years, choosing 20 for publication here was not an easy task. To help the editors sought the assistance of three retired distinguished Caribbean agriculturalists who gave many years of outstanding service in their fields. These persons are:

Dr Patrick Alleyne, former posts included Food and Agriculture Organization (FAO) Head of Mission, Barbados and Eastern Caribbean and FAO Head of Mission, Tanzania; also Permanent Secretary, Ministry of Agriculture, Trinidad and Tobago.

Dr Dunstan Campbell, former FAO representative for Jamaica, Belize and Bahamas and UWI Outreach Lecturer for the Windward Islands.

Dr Samuel Howard, former Associate Professor, University of Trinidad and Tobago and Director of Research, Ministry of Agriculture Trinidad.

The criteria for choosing the papers to be republished was that the articles should have been ground breaking when published with emphasis on (but not completely comprising) Caribbean work. It was decided to include two papers from each decade from the 1920s up to the 2010s. The 20 articles chosen are published in the pages to follow, **in their original formats**, although it must be pointed out that there were dozens of other papers which could have made the final selection.

The first paper published in this special issue is a republication of the first article in the first issue of TA; the second paper reminds us that the principles of biological control were known to the earliest humans. These two papers are followed by description of some early efforts to control Witch's Broom and then the studies in West Indian soils by Professor Frederick Hardy was one of the few unanimous choices by the selection panel.

The 1940s were times when plantation export crops were still the mainstay of West Indian economies and this is reflected by the works on sugar cane and banana improvement. Two tree crops, coconut and mango, were selected for the 1950s. The 1960s articles republished are on soil surveys and ticks affecting cattle.

In the 1970s the late Professor George Sammy pioneered research into value addition in Trinidad and there is another paper on the work of the breeding of sugar cane in Barbados. The 1980s are represented by a paper on modern methods of commercial fruit production and an interesting review of the status of cocoa research in Jamaica.

Another paper on cocoa is published as an example of the 1990s, together with a review of farming systems work which came to the forefront during the last 20 years of the last century. A further paper on small farming systems leads the articles chosen from the current century and this is followed by a detailed study on the management of soils in high rainfall situations.

The last two papers are on breadfruit and yam, emphasizing perhaps the shift from working on export crops to food security crops and the need for tropical populations to increase consumption of tropical crops in preference to imported produce.

Frank Bruce Lauckner
Editor In Chief

Extracted from Volume 1, Number 1, 1924

TRINIDAD CACAO

PROFESSOR W. R. DUNLOP

Industry has its economic maladies just as plants and animals have their biological ones, and this is particularly true of the industry of tropical agriculture. History provides many instances. One has only to recall, for example, the plight (in contra-distinction to the "blight ") of the West Indian sugar industry in the nineties, and the more recent depression of the rubber industry of the East. Both were occasioned by political and economic circumstances and were remedied by political and economic action the first depression by the abolition of bounties and more efficient central factory production; the second by an elastic restriction of production rendered possible by legislation and the commercial co-operation of large interests.

One of the latest maladies in tropical agriculture —and one of a much less impersonal type—is to be seen in the condition of the West Indian cacao industry. The causes of this condition are almost entirely of a psycho-economic nature and they are therefore worthy of careful consideration by everyone concerned with the administrative side of tropical agriculture and development.

In the first place, it is Trinidad—by far the most important of the West Indian cacao-growing colonies and the fourth largest cacao-producing country in the world—that is the most affected, and it is in this Colony that the malady may be studied best.

Briefly the history of the condition is as follows. Some thirty or forty years ago, when the rapid establishment of cacao estates began, it was the recognised local custom to acquire suitable Crown land, freehold, at the usual moderate price, and for the owner to develop a small part of it himself, and most of the remainder by means of the contract system whereby the contractors, usually natives, brought the cacao into bearing and were then paid for the established plantation on a more or less arbitrary basis of valuation of about 4s. per tree arrived at by capitalising the return to be expected under conditions existing at the time. In order to carry out this development and make payment to the contractors, which involved in many cases thousands of pounds, the owners of the estates borrowed money on mortgage. Subsequently, also, in bad years, further mortgages might be incurred. The ultimate result was that the majority of the cacao estates in Trinidad became heavily encumbered; but since the good price of cacao and the bountiful productive powers of virgin soil brought in a large return, it allowed of the payment of a high rate of mortgage interest without inconvenience ; which in its turn provided a profitable investment to the mortgagee, and both parties being satisfied, neither had much inclination to come to any settlement in respect of the principal involved.

This state of affairs proved effective while the necessary economic conditions for making it so were satisfied. But when in 1920 after a bad climatic season the price of Trinidad cacao fell 50 per cent. of what it had been before the war, cacao planters found themselves financially embarrassed. This was aggravated by the fact that the output per acre had been growing less and less which, in the last few years has continued, owing to connative and financial deficiencies in respect of running the estates on sound agronomic lines.

Now while the pre-war level of prices of cacao are not essential for the profitable production of cacao in Trinidad on a well-managed, productive and unencumbered estate, the present price level of some 8 cents per lb (in New York or London) is certainly very near the limit for successful enterprise. This phenomenally low price is attributable to the enormous increase of low-cost cacao in the Gold Coast (which of course, in common with the West Indies has enjoyed Imperial preference), and to the collapse of the Central European markets especially Germany, who, before the war, consumed as much cacao as the United States did at that time. Contributing causes have been the gradual improvement in quality of much of the Gold

0041-3216/2021/030173-174

Coast cacao and also definite changes in formula in the larger chocolate factories in Britain and America, to make use of this cacao as the basic grade for general consumption.

As to whether the price of cacao in general will increase or (what would be equally beneficial for the West Indies) the premium which Trinidad estates' cacao should command—does not come within the scope of this article. Action is being taken in order to try to bring about a rise in price or else to circumvent the present low level if it persists. Trinidad cacao, however, from the point of view of grade occupies a rather precarious position. Marketing results hoped for may, or may not, be achieved. They are at any rate not likely to be achieved immediately, and it is the immediate present that is important in a critical condition such as exists in Trinidad today.

At the time when the crisis began—in 1920—the Government, in order to help the basic industry of the Colony, introduced an Agricultural Relief system of financial aid, and lent money to encumbered estates claiming in doing so first mortgage (even on estates so encumbered). In addition a moratorium was passed making it illegal for mortgagees to foreclose unless payment of interest was withheld beyond a certain time. This latter action was primarily taken to prevent the withdrawal of foreign loans on cacao which in Trinidad are considerable and amount to several hundred thousand pounds. Both moratorium and relief, which are still in operation, are likely to be lifted this year. But unless a sudden and substantial improvement takes place in the marketing aspect; the final result cannot be other than a complete revolution in ownership and industry—which, while conferring hardship and perhaps ruin on many, will probably in the long run be the best thing for the Colony.

It is of course true that the authority of the Colonial Office has been obtained for the establishment of a permanent Agricultural Bank. This institution will lend public money in the form of mortgage loans on an amortization basis, and will advance money also against crops. But even if the capital of the Bank were large enough—which it is not—it could scarcely revivify the cacao industry in its present condition. Estates carry loans against valuations fabulously fictitious at the present time. Indeed much of the present trouble lies in the circumstance that valuations were made on the basis of market prices for cacao, This has no meaning in the sense of intrinsic security for, *reductio ad absurdam*, if the price of cacao falls for a period of years below the cost of production a cacao tree is commercially valueless and the property becomes in theory (and in reality) so much bush covering an impoverished soil. The estate—except for its buildings and communication facilities—has not the value of good Crown land. Hence there is no real security in a cacao estate mortgage, and the valuations of the past in Trinidad have been nothing more than arbitrary estimates of possible revenue.

In conclusion it would appear that the conservation of the industry depends upon an economic adjustment being made between higher yields and lower cost of production. Lower costs can be effected immediately by the elimination of mortgage interest (foreclosure) and reform in management. The specific nature of the reform in individual cases can only be determined by an analysis of the economic structure of each estate by means of cost accountancy and statistical methods. Once estates have been re-started on a sound basis the general adoption of a cost accountancy system involving cost valuation and depreciation, capital and private and reserve accounts, will be the best ethical as well as economical safeguard to future progress.

Extracted from Volume 6, Number 6, 1929

BIOLOGICAL CONTROL

The Principles of Biological Control

BY J. G. MYERS, SC.D., F.E.S.,

Imperial Bureau of Entomology

Probably ninety-nine out of every hundred people, when they think of the contributions of science to human welfare, recall the physical, chemical and mechanical inventions which produced the industrial revolution and are now engaged in the mechanisation of the world, and in the evolution of its new master, the centaur of the new civilisation—that half-man, half-automobile, envisaged by that brilliant recent writer, Woodruff, in Plato's American Republic. We are not accustomed to think of biological inventions; by which we mean, with Haldane, "the establishment of a new relationship between man and other animals or plants, or between different human beings, provided that such relationship is one which comes primarily under the domain of biology, rather than physics, psychology, or ethics." The application of biology to the solution of human problems has as yet hardly begun. Haldane has shown that the number of great biological inventions can be counted on the fingers of one hand, and most of these were made before the dawn of history.

When mankind was at the hunting stage of culture, living only on animals and perhaps a few plants, secured with the aid of primitive tools, a Malthusian prophet might justly have envisaged, concurrently with improvement in weapons and in hunting technique, a gradual decrease and final extinction of the game, and with it the annihilation of the human race dependent thereon. It is improbable that he would have predicted the innovation—the first great biological invention, namely, the domestication of animals and plants—which was to save the future and ensure the continued evolution of man.

It is interesting to realise that until recent years there had not been, during the whole historic period, any noteworthy addition to the list of man's domestic animals. All had been the servants of man from the dawn of history, they had accompanied him out of the mists of antiquity and had materially assisted his emergence.

The principle of biological control involves a tremendous increase in the numbers of man's animal auxiliaries—it is, in fact, an extension of the first great biological invention—the domestication of animals. It is true that the 'animals thus utilized are usually not domestic animals in the strict sense of the term, but there exists every gradation between these and such closely-domesticated organisms as dairy-cows. Moreover, in what were in all probability among the first attempts at biological control—the destruction of rats and mice by dogs and cats—animals probably already domesticated were the agents.

Ferrets, however, used against rats and rabbits, are very much less domesticated than dogs or cats and form a transition to natural enemies which are utilized without true domestication. It is these latter which are the chief agents in the biological control of insect pests.

The term "biological control" covers at the same time, a multitude of sins and a number of man's newest and most promising weapons in his struggle with the organic environment. We must carefully examine these, for with the increasing popularity of natural control methods it becomes more and more necessary to define clearly what reputable workers understand by " biological control," and to distinguish between what should be actually attempted in this sphere, and what must still remain the subject of cautious experimentation. The need is the more urgent from the fact that, as Thompson has recently emphasised, "economic entomology, though it finds in science its principles and its tools, is itself not so much a science as an art, like medicine.

As in medicine, the practice of the art is always to some degree in advance of the written recipes and rules, which hardly do more than catalogue what

0041-3216/2021/030175-178

experience has taught. One consequence of this is that while certain general methods gradually develop, there is a considerable period during which they can be learned only from the practitioners of the trade; another is that their general value remains uncertain until their scientific basis is critically examined. Such is at present the situation in regard to the biological control of insects and pests…"

How, then shall we define " biological control?" In a sense any method of combating a pest by means other than direct chemical or physical ones, is biological. The breeding of immune varieties of plants is one such, very promising, means. We would, however, limit the term to the utilization of one kind of organism for the limitation or destruction of another. The theoretical possibilities of such a method are, of course, extremely numerous, but we shall confine the following analysis to those cases in which attempts have been actually made or suggested. Even for these the accompanying table is not complete; but it will serve as a basis for discussion.

I. Control of Injurious animals.

A.—By other animals.

1. Control of nematodes by predacious nematodes (Steiner and Heinly, suggestion only, 1922).
2. Control of molluscs by vertebrates (slugs and snails by birds, hedgehogs, &c.)
3. Control of insects and other arthropods by
   (a) mites.
   (b) other insects.
   (c) birds.
   (d) other vertebrates (eg. fish and newts against mosquito larvae, toads against nocturnal insects, bats against mosquitoes).
4. Control of vertebrates by other vertebrates (eg. fish by fish, snakes and rats by mongoose, rabbits by weasels, mice and rats by birds of prey).

B.—By plants

1. Control of insects and other arthropods by
   (a) bacterial diseases.
   (b) parasitic fungi.
   (c) algae
   (eg. mosquito larvae by Chara spp.)
   (d) phanerogams
   (eg. scale-insects on lime trees diminished by allowing Bengal beans to climb over. trees. Montserrat, Ballou). (Melina grass against flies and ticks).
2. Control of injurious vertebrates by bacterial diseases (eg. rabbit in Australia, rats).

II. Control of injurious plants (Weeds) by

1. insects (eg. against prickly pear and Lantana).
2. mites (eg. against prickly-pear).
3. fungi (eg. against prickly-pear,blackberry, Californian thistle).
4. bacteria (eg. against prickly-pear).

In addition there are such borderline cases as that of d'Herelle's bacteriophage; and such indirect control as that of cattle flies by the utilization of dung beetles, which render the manure unsuitable for their breeding.

Most of these cases represent actual attempts; a few are only suggestions. As to their relative practicability, it cannot be too strongly emphasised that all are either in the experimental stage or may be dismissed as valueless, save the control of insects and other arthropods by insects. It is far too frequently forgotten that this and this alone is the only sound general practice in biological control. To this must be credited every one of the sweepingly successful applications of the principle. Only when this method has failed after years of trial, should the introduction of natural enemies other than insects (or other arthropods) be contemplated. The introduction and acclimatization of predacious birds and mammals as a measure against pests (whether insect or vertebrate) has led to such disasters in the past, that it should be universally condemned. I need only mention the introduction of the mongoose into the West Indies, of the stoat and weasel into New Zealand, and of the English sparrow into North America and other parts of the world. So far as insect-eating birds are concerned, we should carefully distinguish, of course between the importation of foreign species and the encouragement of native ones which have been found useful to agriculture. As McAtee (1926) has recently shown, the local birds may be looked upon "as an ever-present force which automatically tends to check outbreaks, large or small, among the organisms available to them as food. It is a force which should be kept at maximum efficiency by protective measures and which should be taken into consideration and used whenever possible.”

Bird protection then, both passive, by restriction of killing, and active by establishment of sanctuaries and perches, and checking of ground vermin, may be looked upon as a general insurance against insect outbreaks. It can rarely be considered as a measure against individual pests.

Save that in their case, protection is less practicable, the same remarks apply to insectivorous mammals, lizards and amphibians, the two latter being especially important in the tropics.

The control of weeds by means of their insect enemies is still entirely in the experimental stage. The best known attempt—that directed against Lantana Camara in the Hawaiian Islands, has been successful in that the plant has been largely prevented from seeding by insects introduced from Mexico. By this means its re-infestation of cleared land and its further spread are greatly checked. The prickly-pear (*Opuntia* spp.) in Australia—the most spectacular weed in the world—is also, according to latest reports, gradually succumbing to the attacks of insects and mites imported, on a very large scale, from America.

Numerous observers, in many parts of the world, have been greatly impressed with the tremendous mortality among certain insect pests, under certain conditions, through the attack of fungous parasites and bacterial diseases. And just as numerous attempts have been made to reproduce these conditions artificially, and to control outbreaks by propagating the disease. In particular instances, sweeping successes have been claimed, notably by Le Moult and by d’Herelle, but later observers have usually failed to obtain similar results. One of the most thorough and careful workers in this field, Paillot (1916) came to the conclusion that “la creation d’epidemies artificielles cemparables, en intensite et en &endue, aux epidemies naturelles, soit peu pees impossible dans l’etat actuel de nos connaissances; trop de facteurs interviennent, en effet, dans la propagation de ces epiclanies, qui echappent plus on morns completement l’influence de l’homme.” Petch (1921) a mycologist who is perhaps the foremost authority on entomogenous fungi expressed the same conclusion even more strongly when he said, “ At the present day, after thirty years’ trial, there is no instance of the successful control of any insect by means of fungous parasites. If entomogenous fungi already exist in a given area, practically no artificial method of increasing their efficacy is possible. If they are not present good may result from their introduction if local conditions are favourable to their growth; but, on the other hand, their absence would appear to indicate unfavourable conditions.”

So far as insect pests are concerned—and these are the worst of our troubles, we are thus left with control by means of their insect enemies. But even here, further analysis is necessary before we arrive at what is practicable and promising and what is not. With insectivorous vertebrates we have just seen that importations have usually proved more or less disastrous mistakes while encouragement of local species is recommended as a measure of general insurance. Precisely the opposite has been the case with insect enemies of insects, for here, as noticed above, all the most sweeping successes have been won with introduced parasites, while the attempted encouragement of native ones has usually proved futile.

A consideration of these successes, and notably of those achieved in Hawaii, show that the most favourable circumstances may be summed up under four heads.

1. The pests to be controlled are immigrants, accidentally introduced without their natural enemies.
2. The indigenous fauna is of a limited and peculiar kind, so that the chances of the immigrants finding new enemies in it are very small.
3. The climate is warm and equable, allowing introduced parasites to multiply without seasonal checks.
4. There are only a few main crops, so that high organisation and centralisation are possible, and a small improvement is rendered important by the large scale of operations.

Probably no other part of the world is quite so favourably situated as Hawaii in reference to all four of these conditions. But it is safe to say that any country possessing these four qualities in some degree, is favourably situated for biological control. One would expect that once suitable natural enemies were discovered, imported and established, the task would in most such cases be accomplished. Probably the most unfavourable regions in which to attempt control of this nature lie in continental areas, with a rich and varied fauna, and a "temperate" climate, with a cold winter. In such areas it might be necessary to breed the parasites continuously in the laboratory and distribute them periodically, so as to force them into a condition of permanent dominance, to use the term of H. S. Smith. Such is the method used with the Australian ladybird, *Cryptolaemus monirouzieri*, in California, against the citrus mealy-bug. It is, of course, considerably more expensive than mere introduction and establishment accomplished once and for all, but at least in the citrus industry, it remains less costly than chemical measures of control.

This principle of assisting, as it were, the work of parasites already established, may theoretically be extended to indigenous natural enemies of pests either native or imported. In fact, the large sale utilisation of parasites already present, notably those of the codlin moth in California and of the sugar-cane borer (*Diatraea*) in Louisiana, is one of the latest developments of applied entomology. But such extension, whether on a large or on a small scale, has nowhere yet met with any striking success, and biological control as a whole should not be judged by the trial of it alone. The corollary is that the best results in biological control are to be expected in the future, as they have been obtained in the past, from the introduction and establishment of parasites from other regions.

When we come to the tropics it is often a matter of the greatest difficulty to decide whether a given pest is an introduced or an indigenous insect, and provided the entomologist ascertains exactly what parasites are attacking it in the various regions of its range, this becomes largely an academic question. The sugarcane froghopper in Trinidad, evidently an indigenous insect, has very thoroughly adapted itself to cane-field, i.e. essentially exotic conditions, while its local enemies have very largely failed to do so. The position thus simulates that of an insect introduced into a new country, without its natural enemies, and the way is open for the importation and establishment of foreign parasites which are as well adapted to cane-field conditions as the froghopper itself. The same principle applies to a number of other tropical pests.

A most essential part of the work consists in freeing the imported parasite from its own natural enemies (hyperparasites) before it is liberated. Mistakes of this kind are usually irrevocable. The controversy as to the necessity for a sequence of parasites to attack various stages of the pest insect, with the dangerous tendency to the opposite extreme of super- and co-parasitism, or the injurious competition of several parasites for the same individual hosts, seems now to have been resolved in the policy of sending one or two judiciously selected species at the beginning, and observing their effect, before introducing others. The choice of species to introduce must, in the present state of our knowledge, be left in each case to the judgment of the specialised investigator who can study the pest and its enemies in the different parts of its range.

The emphasis on foreign parasites implies, of course, that the task is not one for the local entomologist to perform single-handed. Biological control offers an extremely promising field for co-operative research, and with the foundation by the Empire Marketing Board of a special laboratory for this work under the Imperial Bureau of Entomology, its rapid further development along these lines, throughout the Empire, seems assured. The mission of the present writer to the extremely promising field of the West Indies is the latest extension of the same organisation.

Extracted from Volume 8, Number 4, 1931

WITCH BROOM CONTROL

A New aspect of Witch broom Control in Trinidad

By *H. R, BRITON-JONES AND F. E. CHEESMAN*

Introduction

This work, commenced in March, 1930 at the request of the Government of Trinidad and Tobago had as its main object the finding of additional means of controlling Witch broom disease (*Marasmius Perniclosus* Stahel) in Cacao With particular reference to the conditions prevailing in Trinidad. The majority of the factors discussed below are however applicable to other countries such as Surinam and Ecuador where up to the present time the disease appears to be much more serious than it is in Trinidad.

The writers have held certain theories in regard to witch broom disease in Cacao since October, 1928, when the disease was first brought to their notice in Trinidad. These theories were based on the one question of paramount importance, namely, whether the spores of the fungus can infect dormant buds as well as those which are already sprouted. Stahel (12) states that "The grown-through and ordinary Krulloten (brooms) originate from infection of buds not yet sprouted. Strong end buds of chupons and of young trees which have not yet branched out and also of strong side-shoots often grow through."

The exact meaning of Stahel's statement is not clear*, but if dormant buds can be infected, the means of control have reached their limit. Indeed it would appear that to cut out a broom-beating branch six inches below the base of the broom might lead to the production of as many as half a dozen brooms to replace the one since the cutting would stimulate the dormant buds below to grow out into shoots. If previously infected they would produce witch brooms.

The production of witch brooms behind the cut end occurs quite frequently at the present time, but not because the previously dormant buds were infected. This will be referred to later. Furthermore, infection of dormant buds would definitely limit the effectiveness of spraying with two percent. Bordeaux Mixture, which has been described as giving effective control of the disease in Surinam. The effect of spraying with Bordeaux Mixture on the disease is also further' discussed below:

Infection Experiments

The following method was adopted for deciding whether dormant buds are infected by *Marasmius Perniciosus*: — Some hundreds of Cacao seedlings which had been raised in bamboo pots were transplanted out in beds of about 4o seedlings each in an established Cacao plantation at St. Anna Estate, Cumuto. These young nurseries were kept free of weeds by hand cultivation and no further treatment was given until they had started to make fresh growth thereby indicating that they had recovered from the shock of transplanting. The young plants varied in height roughly from twelve inches to two feet. When required for inoculation experiments they were cut back to about half their height and just above one or two dormant buds. Some of these were inoculated at intervals of one week, two weeks, and three weeks after cutting back. In each case controls were kept. Thus buds were inoculated at various stages, namely, dormant, swelling. bursting and growing. Inoculation

*As we are going to press Dr. Stahel informs us in an answering letter that he did not investigate the matter of infection of dormant vegetative buds. He also draws our attention to a publication of his which we had missed (Bull. No. 39, Brijdrage tot de kennis der Krullotenziekte. Dept. van denLandbouw. Dec. 1919) in which it is shown that (i) the infection of _the ovary can only take place through stomata which develop after fertilisation. It is highly improbable that any stomata could be exposed on the dormant buds with which we worked, and hence our findings are in accord with his (ii) green brooms can produce sporophores (mushrooms). *Vide* pp. 4 and II in this article. Bulletin 39 does not otherwise affect this article.

0041-3216/2021/030179-195

was done by applying a gill of a fresh sporophore (mushroom) actually on to the bud in the case of those in a dormant and swollen condition and between the stipules and young leaves in the case of those bursting and growing. The gill was then sprayed with water by means of an atomiser and in some cases covered with a large test-tune which had been previously spayed with water to wet it on the inside. In others the shoots were left uncovered.

Inoculation Series No. 1.

All the Cacao seedlings in this series were cut back on the 27th June, 1930. as described above. Whilst inoculation was being carried out heavy rain fell on each occasion.

NO. of Bed Rows	NO. of Plants	Date Cut Back	Date Inoculated	Date finally Examined	Remarks
I.1	4	27/6/30	27/6/30	19/9/30	No Brooms
I.2	4	do.	Control	do.	do.
I.3	4	do.	27/6/30	do.	do.
I.4	4	do.	Control	do.	do.
And so on for 10 rows					
II.1	4	27/6/30	27/6/30	19/9/30	No Brooms
II.2	4	do.	Control	do.	do.
II.3	4	do.	27/6/30	do.	do.
II.4	4	do.	Control	do.	do.
III.1	4	27/6/30	27/6/30	19/9/30	No Brooms
III.2	4	do.	Control	do.	do.
And so on for 9 rows					
IV. 1	4	27/6/30	11/7/30	19/9/30	2 brooms 1 healthy 1 doubtful
IV. 2	5	do.	Control	do.	No brooms
IV. 3	5	do.	11/7/30	do.	2 brooms
IV. 4	5	do.	Control	do.	No brooms
IV. 5	3	do.	11/7/30	do.	No brooms
IV. 6	4	do.	Control	do.	No brooms
IV. 7	3	do.	11/7/30	do.	2 brooms
IV. 8	4	do.	Control	do.	No brooms
IV. 9	5	do.	11/7/30	do.	2 brooms
IV. 10	3	do.	Control	do.	No brooms. On the 11th July, 1930, buds in first stages of growth but varying between swelling and bursting

There were 20 plants inoculated in Bed IV of which eight or 40 per cent were positively infected. Beds Nos. VI, and VII were also cut back on the 27th June, 1930, but inoculations on the 18th July, 1930 and on 25th July, 1930 were not possible owing to the difficulty of finding mushrooms. A period of dry weather had set in which is quite abnormal at this time of the year.

Inoculation Series No. II

Four additional beds were treated in a similar manner to those in Inoculation Series No. I. All plants in the four beds were cut back to dormant buds on the 22nd September, 1930.

Bed No. 1.—Inoculated 22nd September, 1930. This consisted of ten rows of ten plants each. Rows I, III, V, VII, IX inoculated as in Series No. 1., sprayed with an atomiser but not covered with a test-tube. Rows II, IV, VI VIII, X served as controls. Examination on 21st November, 1930, showed that all shoots from inoculated and controls were healthy. No Brooms.

Bed No. I I.—Inoculated 26th September, 1930. Rows I, II and III, 4 plants each. Inoculated. Covered with test-tube for 24 hours. Test-tube then removed. Rows IV and V, 4 plants each. Controls. No brooms on 21st November, 1930.

Bed No. I I—.Inoculated 3rd October, 1930. Most of the buds showing signs of swelling. Rows VI, VII, and VIII, 4 plants each. Inoculated. Not covered with test-tube. Rows IX and X, 4 plants each. Controls. No brooms on 21st November, 1930.

Bed No. I I I.—Inoculated on 10th October, 1930. Some of the buds were swelling, some bursting, and others actually growing. In the following table-diagram the inoculated buds are indicated thus :--

Row I	-	S	G	S
Row II	B	B/G	B/G(B)	S
Row III	S	G	G (B)	-
Row IV	S	B	S	B
Row V	S	S	B/G	G (B)
Row VI	S	S	G (B)	S
Row VII	S	S	S	S
Row VIII	S	B	B	G
Row IX	S	S	S	S

R =bursting, G= growing and B/G= a stage intermediate between B and G. Those marked S served as controls although in swelling stage only.

All plants sprayed with water. A shower of rain fell immediately after inoculations had been completed.

On 21st November, 1930 those showing brooms are marked (13). No. inoculated=14, Number of positive infections =4.

Bed No I V.—Inoculations on 17th October, 1930. Procedure as in Bed No. III. Controls varied in condition ranging from B, B/G to G. Inoculated buds as indicated.

Row I	B/G	B/G	G	G
Row II	Not included	Not included	G	G
Row III	G	B/G	B/G	Not included
Row IV	B/G	B/G	B/G	B/G (B)
Row V	B/G	B/G	B/G	B/G
Row VI	Not included	B/G (B)	G	B/G
Row VII	Control	Control	Control	Control
Row VIII	Control	Control	Control	Control
Row IX	Control	Control	Control	Control

Positive infections 2 indicated by (B). No. of inoculations 20.

Note—The results in Inoculation Series No. II arc not conclusive because at the time of inoculation of Bed I, II and IV the weather was dry so that failure of inoculations in Beds I and II might quite easily be due to unfavourable conditions.

Inoculation Series No. III

Twelve young Cacao plants growing in bamboo pots were cut back to dormant buds. By the 28th November, 1930, these had produced shoots varying in length between one to two inches, and at 3 p.m. were inoculated as in Inoculation Series I, sprayed with water, and covered with a large test tube. At 10 a.m. on the 29th November,1930, the tubes were carefully removed, the plants again sprayed, and tubes replaced as before until 11 a.m., on the following day when they were finally removed.

On the 28th November, 1930, ten more young Cacao plants in bamboo pots were cut back to dormant buds, inoculated at 3 p.m. by placing half a mushroom on the dormant buds near the cut end. These were kept in place by wrapping in moist cotton wool which was then thoroughly wetted by spraying with water. They were then covered with test-tubes and further treated as in the case of the above 12 plants.

WITCH BROOM CONTROL

PLATE I

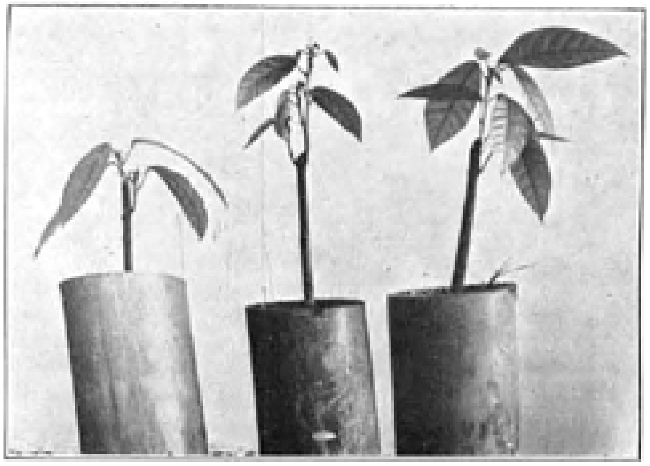


FIG. 1.— Inoculated Plants with growing shoots in Inoculation Series III on 17th December, 1930 showing first stages of broom development. Left to Right, Plants IX, X and I.

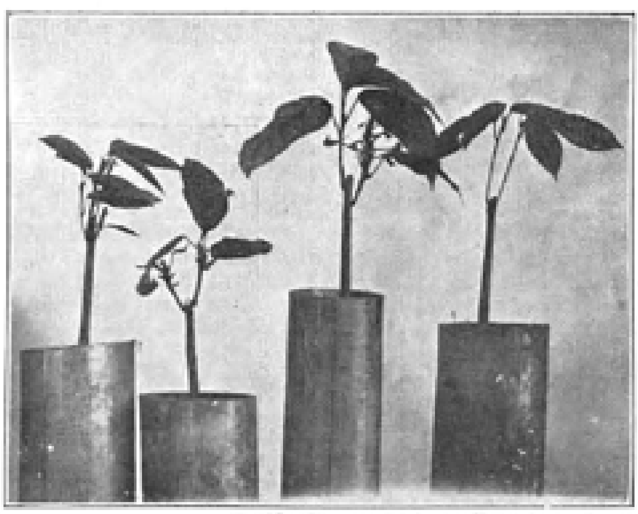


FIG. 2.— Inoculated Plants in Inoculation Series III on 3rd January, 1931. Left to Right, Plant II of series inoculated with buds in clamant stage-shoots normal. Plant X and Plant I as in Fig. I.

PLATE II

FIG. 1.—As in Plate I, Fig. 1. Plant X on 17th Decentber,1930.

FIG. 2.— A branch of Cacao tree showing marked variation between size of leaves on lower and upper sub-branches. Note thicket of growth at top.

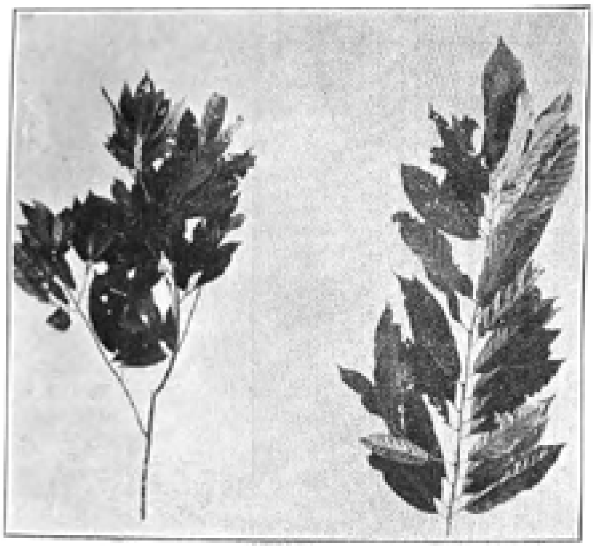


FIG. 3. — Left—sub-branch of branch in Plate I I, Fig. 2. Right—Branch from same tree. Note the differences in the sizes of the leaves on the two branches.

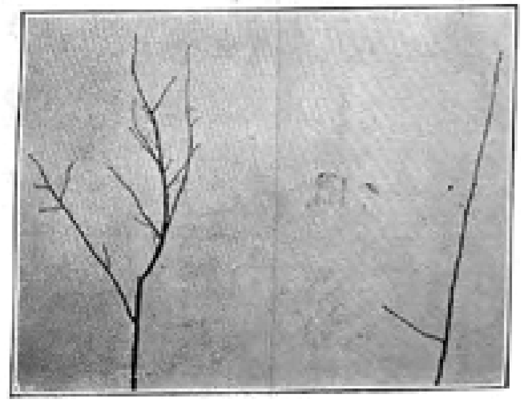


FIG. 4.— A s in Fig. 3 with leaves removed. Note difference in numbers of growing points. Branch on left which had small leaves has 21 growing points whereas branch on right has only two.

The following records observations carried out on the foregoing plants :

Plants with Growing Shoots inoculated

No of plants	No. of Shoot	Date 5th Dec., 1930	Date 12th Dec., 1930	Date 17th Dec., 1930	Date 22nd Dec., 1930	Date 28th Dec., 1930
I	1	Apparently Healthy	Top inch slightly swollen. Broom	Broom	Broom	Broom
	2	Do.	Apparently Healthy	Apparently Healthy	Broom	Broom
II	1	Do.	Apparently Healthy	Apparently Healthy	Apparently Healthy	Apparently Healthy
III	1	Do.	Apparently Healthy	Apparently Healthy	Apparently Healthy	Apparently Healthy
	2	Do.	Top 3/4 inch slightly swollen. Broom	Broom	Broom	Broom
	3	Do.	Top 1/2 inch slightly swollen. Broom	Broom	Broom	Broom
	4	Do.	Apparently Healthy	Apparently Healthy	Apparently Healthy	Broom
IV	1	Do.	Apparently Healthy	Apparently Healthy	Apparently Healthy	Broom (2nd January, 1931)
	2	Do.	Do.	Do.	Do.	Broom
V	1	Do.	Apparently Healthy	Apparently Healthy	Apparently Healthy	Apparently Healthy
	2	Do.	Do.	Do.	Do.	Broom
VI	1	Do.	Apparently Healthy	Apparently Healthy	Apparently Healthy	Broom
	2	Do.	Top 1/2 inch slightly swollen. Broom	Broom	Broom	Broom
	3	Do.	Apparently Healthy	Apparently Healthy	Apparently Healthy	Apparently Healthy
VII	1	Do.	Apparently Healthy	Apparently Healthy	Broom	Broom
	2	Do.	Do.	Do.	Broom	Broom
VIII	1	Do.	Top inch slightly swollen. Broom	Broom	Broom	Broom
	2	Do.	Apparently Healthy	Broom	Broom	Broom
IX	1	Do.	Apparently Healthy	Apparently Healthy	Apparently Healthy	Apparently Healthy
	2	Do.	Do.	Broom	Broom	Broom
X	1	Do.	Apparently Healthy	Apparently Healthy	Apparently Healthy	Apparently Healthy
	2	Do.	Axillary buds Swollen	Broom	Broom	Broom
	3	Do.	Apparently Healthy	Apparently Healthy	Apparently Healthy	Apparently Healthy
XI	1	Do.	Top 3/4 inch slightly swollen. Broom	Broom	Broom	Broom
	2	Do.	Do.	Broom	Broom	Broom
XII	1	Do.	Apparently Healthy	Apparently Healthy	Apparently Healthy	Apparently Healthy

Total number of shoots on 5th December,1930 =28.
Do. do. brooms on 5th December, 1930 =Nil.
Do. do. brooms on 12th December, 1930 =6+1 ? (Plant X Shoot 1),
Do. do. brooms on 17th December, 1930 =10.
Do. do. brooms on 22nd December, 1930 =13.
Do. do. brooms on 26th December, 1930=16
Do. do. brooms on 2nd January,1931 =18.

The foregoing results show that a shoot may be infected for several weeks before it shows any external symptoms in the form of a swelling of the stein or axillary buds. The length of time between inoculation and recognition of the first symptoms of broom formation depends on the rate of growth of the shoots. A rapidly growing shoot shows the symptoms comparatively soon whilst a slow growing shoot must make a certain length of extension growth before the swollen stem is produced and becomes discernible. The significance of this observation will be discussed later.

Two of the ten plants whose buds were inoculated at dormancy failed to make any growth. This failure of a certain number of plants cut back in the same manner and not inoculated is quite common. The remaining eight plants produced between them a total of 15 shoots all of which grew perfectly normally and with no sign of swelling of the stein throughout the experiment. (*Vide* Plate I Fig. 2.)

The results of the above inoculation experiments show that dormant buds cannot become infected by the spores of *Marasmius fierniciosus*. Only those which have already made growth can become infected.

Laboratory Experiments with Brooms

On the 14th March, 1930, bundles of brooms were placed in a series of desiccators containing water to which had been added 10, 15, 20, 25 and 30 per cent. sulphuric acid. In this manner the brooms were constantly kept under different degrees of humidity ranging from 100 per cent, to about 75 per cent. In a few days all the brooms showed a whitish growth of saprophytic fungi belonging mainly to the genus Fusarium. It was, therefore, decided to divide the bundle in each of the desiccators into two. One half was dipped daily for a few seconds in alcohol acetic in order to keep down surface fungus weeds.

The other half was left untreated. Both treated and untreated were kept in the desiccators for over seven months but during this lengthy period there was no sign of sporophore (mushroom) production by the Witch broom fungus. It was then decided to subject the bundle, which had been treated with a fungicide and kept at approximately 90 per cent, humidity, to intermittent but prolonged showers of tap water from a spray nozzle in the laboratory. At the end of a fortnight one of the brooms produced three mushrooms the smallest of which measured about half an inch and the largest almost an inch in diameter. A week later another broom from the same bundle produced one mushroom about three quarters of an inch in diameter. This is the first time this fungus has been induced to produce fructifications under laboratory conditions.

It appears, therefore, that atmospheric humidity is not the factor which governs sporophore production. It has been conclusively demonstrated that this occurs only when brooms are subjected to frequent showers of rain or tap water.

An experiment was carried out in the field to ascertain whether brooms which had been removed from the tree whilst in a green state could produce mushrooms. For this purpose bundles of green brooms and brown brooms were placed separately on the ground at weekly intervals to see whether there would be any difference between the green and the brown brooms in regard to mushroom formation and to ascertain the period of time for the production, if any, of mushrooms. This was continued for three months and no mushrooms were produced on either the brown or green brooms. At the end of this period all the bundles were unfortunately inadvertently destroyed.

It is important to find out whether green brooms can possibly under any conditions produce mushrooms. A negative result would reduce considerably the cost of present control measures and would stimulate planters to cut green without the additional expense of collecting and destroying. It was also desirable to ascertain whether brown brooms require a resting period with or without rain before they produce mushrooms in wet weather. Up to the present no conclusive results have been obtained in regard to these two points. In view of their importance in connection with the control of witch broom disease they will, however, be thoroughly investigated later.

The longevity of the life of the broom is indicated by the fact that after a period of over seven months they are still able to produce mushrooms.

Effect of Weather Conditions

Records of the incidence of Witch broom collected by the Department of Agriculture of Trinidad and Tobago as well as those kept by individual planters show that there is a sudden increase following the breaking of the rains in May or June which continues in a general way until the “petit carême” (Indian

Summer) in September and October. During the "*petit carême*" the weather is drier and this is accompanied by a sudden drop in the numbers of brooms found in affected areas. Later, when this short dry period is over there is gain a sudden increase in the number of brooms. As already pointed out by Stahel (12) in Surinam and Sten (14) in Trinidad this sudden increase and decrease is due to the fact that the sporophores (mushrooms) of the fungus arc not produced under dry condition.

This is the direct effect of weather conditions on spore production—one factor essential to the spread of the disease. Besides this, the advent of the rains in May and June brings about, in Cacao as well as in other plants, a flush of growth which involves the bursting of buds which have hitherto been dormant. These buds, on developing, become for the first time liable to infection. The number of dormant buds which grow out at this time depends on several factors.
Cacao in Trinidad defoliates during the long dry season and generally speaking this is followed by a flush of growth about six weeks later. If the dry season is prolonged the amount of extension growth and the period during which this takes place is less than under more favourable soil moisture conditions. When the rains in June follow such a dry period there is a sudden uptake of water by the roots and the response to this by the Cacao is not confined to the further production of extension growth, but it also stimulates into growth the dormant buds behind the growing points. Thus the production of sporophores at the commencement of the wet season coincides with the stimulation into growth of dormant buds which then and only then become liable to infection.

Defoliation

It has already been stated that the incidence of witch broom depends to a large extent on the time at which Cacao produces a flush of new growth. This is not wholly but is to a great extent preceded by partial or complete defoliation about six weeks earlier. The date of defoliation although occurring in a general way more or less at the same time over large areas does, nevertheless, vary to no mean extent between different estates and between individual trees even in the same field on the same estate. It is not proposed to attempt to explain all the reasons for this variation but there are certain important factors which contribute to it and which cannot be passed over without comment.

One of the main group of factors one can indicate under the complex term " Soils." The plural " Soils" is used to focus attention on the various types of soil on which Cacao is being grown in Trinidad. In addition to the intrinsic properties of the various types of soils which influence to different extents the amount and time of growth of Cacao, must be considered the management of these soils. Planters differ in their opinions as to the treatment these soils should be given. Interlocked with this to a great extent is the question of finance since one, attorney in charge of half a dozen estates can give good treatment to the soil on one or two, but is forced by economic pressure to neglect the others against his better judgment from the agricultural point of view. In addition to the matter of type of soil the following factors which are discussed below and which, it must be remembered, often interact on each other, also influence defoliation in Cacao: drainage, windbreaks, shade, humidity, thrips, pruning, type of tree and position of estate in relation to prevailing winds.

Drainage

Went, van Hill, Drost, Stahel (I2) and Steil (14) agreed that an improved system of drainage would not have a direct beneficial effect in reducing the incidence of witch broom since the disease affects both strong and weak trees. They also point out however that it would make the Cacao trees more tolerant to the cutting out of brooms.

The present writers agree, but consider that good drainage is of far greater importance in its influence on the incidence of Witch broom than is thought by the above mentioned workers. When Witch broom first appeared in Trinidad it was stated (7) that the disease occurred mainly on low lying ground with a rainfall of about 100 inches and that the disease was worse near the river banks. The reason for this was due to the fact that the river took its course along the lowest points so that the Cacao growing on the banks was not so well drained since in the months of heavy rains the river overflows its banks.

Coupled with the fact that the trees on the banks were not so well drained comes the important factor of humidity within the Cacao crop. The humidity of the atmosphere within the Cacao crop is much higher on poorly drained land than on similar land with the same rainfall but well drained. This means that the brooms remain wet for a longer period after a shower of rain. Experience has shown that the longer the period during which brooms are kept wet with water, the sooner will they produce mushrooms. Furthermore, evidence goes to prove that the mushrooms and spores cannot withstand desiccation for any length of time so that any factor which appreciably increases the rate of evaporation of rain water is of importance. One of these factors is good drainage. The weather in Trinidad in the rainy season is showery with intermittent spells of bright sunshine. The spores of the fungus will germinate in water in about thirty minutes and these in order to produce infection of shoots must germinate between the youngest unfolding leaves at the growing points. The youngest leaves have numerous capitate hairs which tend to hold up the rain water and dew. In an atmosphere of high humidity they would keep wet for a longer period than in a drier atmosphere. In other words the influence of good drainage on the microclimate of the growing points is of great importance in connection with this disease.

As will be shown later the writers, are also convinced that it is a factor of much importance in controlling the disease on account of its influence on the type of growth made by the Cacao trees. They wish to point out that the prevailing idea that the deeper the drains the better the drainage system is quite erroneous. It must be remembered that a dry season follows the wet. Deep drains may lead to excessive drying out in the dry season and so cause much more damage during this period than benefit in the wet season. In other words maximum draining is not the optimum. For more detailed discussion on this point the reader is referred to (2) in the list of references.

Shade

Before discussing the vexed question of shade in Cacao the writers hasten to state that no change of shade conditions should he contemplated in Trinidad until it has first been decided not only that the best practicable method of drainage has been put into operation, but that sufficiently long a period be allowed to elapse for the Cacao trees to respond to the change. Further, as already stated by Steil (14) no drastic reduction of shade should be made in one season. Drains should not be deepened more than nine inches or so in any one season, particularly on heavy clays. Any drastic and sudden changes will be followed in some cases by the death of certain of the Cacao trees and in others by attacks of Thrips (t) and dying back of branches.

Concerning the general question of shade in Cacao, Nowell (9) states as follows: “ These effects of rainfall, of depth of soil, and of dry seasons all depend on the conservation of moisture, and to some extent this is capable of being artificially regulated by the traditional method of growing trees for shade. The question of shade or no shade is often debated as though it were capable of a single and universal answer, whereas it depends entirely on local, and sometimes very narrowly local conditions.”

The truth of the above statement is appreciated by a great many, but nevertheless there are others who will persist in advocating the reduction of shade under conditions of soil and exposure to wind which the Cacao cannot tolerate. The exact effect of light on plants is not so far completely understood. Reduction of shade increases the amount of light not only in intensity but in daily duration, and so changes the photo periodicity. It also reduces the atmospheric humidity within the crop, thereby causing increased transpiration. This means that more water is taken up from the soil per unit of transpiring surface. There may, however, be a compensating factor introduced at this stage on account of the differences in texture in the leaves of Cacao produced under heavy, light or no shade conditions. It must also be borne in mind that shade trees take up water. These factors arc compensating in their effect on Cacao in both wet and dry seasons although in different directions. The influence of shade on atmospheric humidity is of much importance since several kinds of plants in Trinidad show symptoms of temporary wilting before the available soil moisture is materially reduced. This is particularly noticeable when the humidity is low and when a breeze is blowing. There is also the possibility that the differences in the temperatures of soils under shaded and unshaded Cacao may be of considerable importance.

The above points are raised to indicate in part the writers’ appreciation of the gaps in knowledge at the present time in regard to shade requirements in Cacao as well as other crops. Apart from wind breaks and the correct situation of the Cacao with respect to the prevailing wind, one of the main requirements before reducing shade is the improvement of the soil conditions. Otherwise it is quite probable that reduction of shade will result, with or without the aid of Thrips, in defoliation followed by a flush of growth just at the wrong time of the year, thereby increasing the amount of Witch broom disease immediately afterwards, although at certain other periods of the year the incidence may be reduced.

A critical time in this respect is the "petit carême" Indeed if by improvement of soil conditions it were possible to avoid defoliation in the "petit carême" and to produce defoliation in the long dry season only it would do more towards the control of Witch broom disease than anything which has so far been done. The writers are of the opinion that this is possible to a great extent since individual trees which are growing in good soil do this at the present time. Reduction of shade which would then be possible would also probably materially change the amount and ratio of soil micro-organisms which would increase the fertility of the soil. The writers also wish to point out that much can he done to keep down the height of the Cacao trees by lifting the heads of the shade trees by pruning.

Spraying

The several investigators of Witch broom disease are somewhat divided in their opinion as to the effects of spraying against the disease. Van Hall and Drost (15) found no beneficial result and this they attributed to the impossibility of reaching all parts of the trees and to the fact that Cacao formed new branches during most of the year.

They, therefore, advocated pollarding (inkappings methode) as a means of control. Ter Lavg (12) on the other hand claims that by spraying and by removing the diseased parts, he succeeded in getting a state almost free from the disease without pollarding. Rorer (11) concluded that spraying with Bordeaux Mixture as was done by for Laag was a more rational method of control than the pollarding of the trees. Stahel (12) on the other hand recommends (1) thinning out of branches, especially in the inside of the crown; (ii) cutting out and destruction of diseased parts. Steil (14) considers that in the dry season, after collecting the Witch brooms, " stone " pods and diseased cushions, it should be sound policy to spray the trees with Bordeaux Mixture or other fungicide should one more effective be forthcoming.

When there are two definite schools of thought concerning a matter of this kind the writers have frequently found that there is an element of truth in both views and that what is most required is to give an explanation of the different findings. In this case both sets of workers have considered the effect of the application of Bordeaux Mixture on the fungus only and not its important effect on the host plant Cacao. The writers agree entirely with Van Hall and Drost on the impracticability of spraying with Bordeaux Mixture against Witch broom disease for the reasons put forward by these authors. Spraying against the fungus to be effective would have to be done in the wet season when the spores are numerous. It is obvious that if an extensive spraying programme—and no other would meet the case—were undertaken in the wet season that most of the spray would be washed off before it even dried on the trees. Now that it has been established that dormant buds cannot become infected it is difficult to understand the object of spraying in the dry season against a fungus which produces but few spores at that time of the year. Weather conditions would effectively control the spread of the disease and the time and money spent in spraying, would be far more beneficially spent on the removal of brooms as is at present being done in Trinidad. On the other hand, it is quite conceivable that spraying with Bordeaux Mixture at the beginning of the dry season might give beneficial results. One of the effects of spraying plants with Bordeaux Mixture is to make the leaves a darker green and prolong their life. This is true of Cacao and would, in the short dry season, effectively reduce the amount of Thrips damage and consequent defoliation and later flush of growth with the coming rains. Spraying at the beginning of the long dry season would further tend to make Cacao carry its leaves well into the dry season so as to produce its first main flush at the height of the dry season when spore production is at its lowest.

The writers whilst putting these points as an explanation of Ter Laag's good results with Bordeaux Mixture do not advocate its use either as a direct or indirect method of controlling Witch broom disease. Spraying Cacao is expensive, difficult, and in the majority of cases the labour and water supply are not available to carry it out to any extent. The chief objection to it, however, is that it merely begs the question and tends to cloak over the fundamental and inevitable issue, namely, the improvement of the soil. When the soil is improved, the root range of Cacao will be deepened on account of improved drainage when heavy rain is falling.

This in itself will mean increased tolerance to drought conditions by the Cacao and when coupled with the increased retentiveness of moisture by the soil its effect will be enhanced.

Furthermore, effective drainage systems which are now impossible in many cases will become a practical possibility and reduction of shade which is admittedly beneficial for many reasons where possible will be tolerated by the Cacao under improved soil conditions.

The writers have investigated spraying as a means of obtaining universal defoliation at the right time in the dry season. This has not met with any success because like Arabian Coffee, Cacao in leaf can withstand high concentrations of winter washes as used in temperate climates.

Type of Tree

Stahel (T2) states that " The Surinam Cacao trees are not all equally susceptible to the disease. There are individual trees which always have more Krulloten than others, whether this peculiarity is hereditary is unknown. I do not think it advisable to select the less susceptible varieties, as it would be more profitable to search for the best bearing trees, without regard to Krulloten which we can control successfully."

Jacquet (6) puts forward the view that infection largely depends upon the physiological weakness of the trees and in support of this describes in some localities serious attacks on poorly grown trees in the wet season when the thin layer of fertile soil became waterlogged. He also records that in certain highland regions in Surinam and French Guiana, where good methods of cultivation are practised and the trees are mostly without shade, the disease is unknown.

Ciferri (20) describes an economically unimportant disease of Cacao tentatively called "roncet" because of its external similarity to "roncet" or "court noue" of the vine. The young shoots on affected trees grow very little and have very small leaves which never reach normal size, though comparatively long and thin twigs may be formed resembling Witches' brooms and bearing a few small leaves. The most apparent symptom at an advanced stage is a reduction in the number of leaves, which are clustered at the tips of the branches and gradually shrivel in the interveinal spaces. Such trees may still produce flowers but generally they do not set fruit or the young fruit becomes mummified. The author considers the trouble to be of a degenerative type.

The above observations by Stahel, Jacquet, and Ciferri have much in common with what has been observed by the writers in Trinidad. On the other hand, there are important differences between the conclusions drawn by Jacquet and Ciferri and the writers. In order to facilitate the explanation of these differences it is considered desirable in the first place to state some funda-mental truths in regard to many fruit-producing plants such as the Tomato, Coffee, Apple, Pear, Avocado Pear, Citrus, Gooseberry, Mango, &c., and to give evidence that this is also true of Cacao.

The facts are as follows:-

(a) Plants which are growing under conditions conducive to the production of only a small amount of vegetative growth are unfruitful.

(b) Plants which are growing under conditions conducive to the production of a medium amount of vegetative growth are fruitful.

(c) Plants which are growing under conditions conducive to the production of a large amount of vegetative growth are unfruitful. In other words it is possible to grow a crop like Cacao under too poor and too rich conditions of growth for the continued production of the maximum amount of fruit.

Adverse conditions for growth have a definite effect on Cacao trees in that the leaves become very much more numerous per unit length of branch and at the same time are very much smaller in size. Coupled with this is the shortening of the internodes and an increase in the number of side branches produced, so that the whole tree has the appearance of a Witches' broom as the term is applied generally to the phenomenon in plants other than Cacao. Given then two trees of equal size above the ground, the good bearing tree will have larger although fewer leaves, longer internodes and fewer branches so as to give the impression of more open formation. The weak tree in comparison will have many short spindly branches bearing small leaves.

This means that per unit area of surface above ground the weak tree will have a far greater number of growing points than the good tree and therefore has of necessity an equally greater number of possible infection points. In addition to the fact that they are, therefore, more liable to become infected with witch broom disease can be added the all important fact that they are what one might call non-thrifty trees, that is, they do not bear as heavy crops as the trees with open formation and large leaves. Another factor which is of great importance is that these non-thrifty trees are generally left unpruned because planters consider that there is nothing on them worth pruning, and that a good many will die if hard pruned. Such trees as a group would come under class A above and in a class intermediate between A and B, namely A/B.

In other words individual trees vary enormously in degree of poverty and further the cause or causes of poverty may be different. For instance there are Cacao trees which have numerous spindly branches with small leaves which are yellowish green in colour, others are similar in appearance except in one important point, namely, the small leaves are dark green and again there are Cacao trees one branch of which bears fruit and larger leaves and will be classified as B whilst the other branches have small dark green leaves and numerous side branches.

It is desirable at this stage to point out that the genetic constitution of different varieties of Cacao may govern to an appreciable extent the size and type of growth as well as make for greater metabolic plasticity, or in other words greater tolerance of unfavourable soil and other conditions. These are of great importance in Cacao as in other crops and are receiving the attention of one of the writers at the present time.

On the other hand the writers consider, in view of the evidence given below, that a large percentage of the Cacao trees in Trinidad belong to Class A and the intermediate Class A/B because they are growing under unfavourable conditions particularly in regard to soil and pruning,

Ring-Barking

One of the four branches on a young Cacao tree which had not previously produced a crop was ring-barked in the first week of November, 1930. When examined in the first week of January, 1931, the branch which had been ring-barked together with its sub-branches were bearing many blossoms. Those branches which had been left untreated showed no trace of blossom. This shows that a check given to a rapidly growing branch will throw it into a fruiting condition. In other words, the ring-barked branch was converted from the Class (C) type to the Class (B) type described above.

Size of Leaf

Plate II Fig. 3 shows two branches taken from the same tree. Similar instances can be seen on a very large number of trees throughout Cacao estates in Trinidad. This shows that in the majority of cases small size of leaf is due to coalitions of growth and, therefore, modifiable.

Inoculation Period

Inoculation Series III shows that there is marked variation between the date of inoculation and the development of a broom on different branches. This has been shown to be correlated with rate and strength of growth. The variability in the period of inoculation between infection and appearance of the broom is of importance since it means frequent inspections by the Witch broom gangs on estates. In other words, although not so serious, it tends in the same direction as would be the case if dormant buds were capable of infection. On the other hand, it will be readily appreciated that trees in a state of crop production (Class B) will be very much less affected in this way than trees in Classes A and A/B. because the side shoots will be fewer and stronger. For the same reason trees in Class C will be less affected even than Class B.

The above leaves no doubt that by adequate treatment it is possible (i) to induce a large number of Cacao trees which on first glance might be taken as a genetic type to make new and a mare desirable type of growth and (ii) to cause partial inhibition of vegetative growth thereby inducing the Cacao trees to produce fruit. The number of Cacao trees in Trinidad which can be classified as A and A/B is surprising and apart from witch broom disease it is evidently very desirable to bring back or convert such poor trees to bearing condition. In regard to the incidence of brooms on good and poor types of trees the following points are significant:—

(i) Trees which are actively vegetative have comparatively few growing points. Other things being equal such as time of defoliation, &c., the incidence of brooms on these trees is proportional to the number of growing points.

(ii) Trees which are in a cropping condition have a medium number of growing points which make a medium length of growth. Other things being equal the incidence of brooms on these trees is proportional to the number of growing points. As a class they are more badly affected therefore, than (i).

(iii) Trees which are weakly vegetative but non-excessively so have a larger number of growing points than (i) and (ii). Other things being equal the incidence of brooms on these trees is proportional to the number of growing points. As a class they are more badly affected, therefore, than (1) and (ii).

(iv) Trees which make but little or no vegetative growth have a larger number of growing points than (i) and (ii) and fewer than (iii). In spite of this, incidence of brooms is less than on (i), (ii) and (iii) since vegetative growth is essential before brooms and incidentally pods can be produced.

(v) Cacao trees in lastro (secondary bush) are less liable to witch broom infection because (a) they are protected by a heavy canopy of vegetation which protects them from falling spores and (b) they do not defoliate so frequently as Cacao under cultivation. Another point in regard to the poor types of trees - (iii) is that they produce weak spindly growth and therefore small brooms also which are very difficult to find in the thicket of branches on such trees. The swollen brooms on the more robust trees (ii) with open formation are more easily detected by the inspection gang.

Pruning

Went (12) stated that on estates where the trees are pruned, comparatively few brooms are found. Steil (14) has pointed out, that annual pruning is beneficial in Cacao cultivations in Trinidad. There are several methods of pruning practised and these methods vary in degree as well as in time of application. Very good results follow the practice of pruning when carried out along certain lines under close supervision. On the other hand the pruning is done in terms of fields of Cacao rather than in terms of individual trees. That is, the same method is often carried out in the same manner irrespective of the fact that not only does each tree require to be judged as an individual in its requirements but also each branch with reference to other branches on the same trees. As with the majority of other plants there is no hard and fast method possible and what must always be done is to apply certain principles with judgment and discretion. The general tendency in the island is, however, to prune too lightly and later to thin out the side branches either too drastically or not at all.

Thinning out of branches some months after pruning in the long dry season is essential, but this must be done with judgment. In connection with Witch broom disease, it is necessary in this thinning to do so in a manner which will effect the minimum amount of new growth subsequently produced. The less new growth of side branches produced in the wet season the fewer the number of vulnerable growing points. When pruning established Cacao plantations it is necessary to consider also the interval at which the trees have been planted. In comparatively young plantations the branches of the trees grow into one another.

In avoiding this the practice of lopping off the ends of the branches at the lowest point at which they interfere with the neighbouring tree is quite unsound. This is nearly always followed by the growth of several shoots from the nodes behind. These shoots grow vertically and in the aggregate make too dense a growth. They also tend to fill up the centre of the trees which is admittedly an unsound thing to do on account of Black Pod and Witch broom disease. It is better to thin out some of these branches by cutting back to their bases. If the parent branch is also interfering with its neighbour this should also be cut cle tn at its base and if the wound is large it should be dressed with carbolineum, brunolinum, or some such effective fungicide.

There is nothing to be gained by allowing trees to grow into each other and all effort should be made to keep them within the space allotted to them. Attention is also directed to the necessity after a number of years for the thinning out of trees. The selection of trees to be left could well be based on the types in the plantation rather than to any stereotyped thinning out in regular intervals. This would reduce the amount of Black Pod and Witch broom diseases and so increase appreciably the yield on pathological grounds alone. It would also give the thrifty or high yielding trees remaining, more room for development and therefore heavier production on cultural grounds also apart from the factor of disease.

In dealing with the question of thinning it might be as well to point out that the practice of cutting out brooms at a point six inches or so below the extent of the affected area whilst effectively removing the broom does in many instances do as much harm as good. The cutting as practised is invariably followed by the production of several shoots behind the cut end and time and again the writers have observed that a clump of brooms will be produced on account of the subsequent infection of the young developing shoots.

There is no alternative method in some instances particularly in the case of leading shoots but in the case of side branches they should be cut to their bases. This is not followed by so much growth of fresh shoots and in a large number of cases particularly when such growth is young and succulent no new growth will be produced.

It will thus be seen that the following points are of great importance and if followed will be found helpful to planters in deciding their method of pruning. By semi-pollarding is meant the removal of all growth up to one inch in diameter.

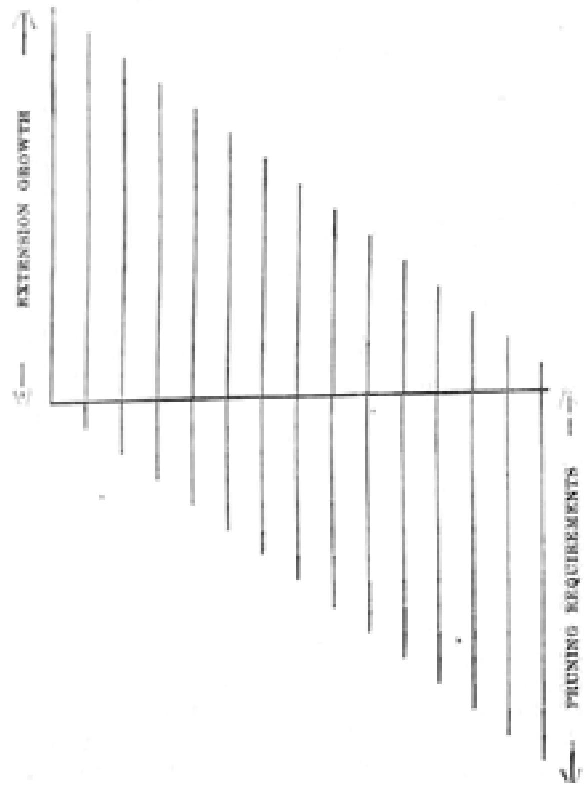
(i) If the cacao tree or branch is producing large leaves and vigorous growth, not prune in the sense of cutting back but thin if f necessary by cutting some of the branches to their bases. Do not manure.

(ii) If the Cacao tree or branch is producing large leaves and medium extension growth together with cropping, resort to medium pruning and medium manuring.

(iii) If the Cacao tree or branch is producing numerous small dark green leaves and many spindly side branches, subject it to semi-pollarding or hard pruning whether it is cropping or not and design the future scaffolding of the tree by thinning some months later. Apply manure:

(iv) If the Cacao tree or branch is producing numerous small light green leaves and many spindly side branches attention should be first paid to the soil conditions. When these have been rectified by improved drainage, manuring, then subject it to semi-pollarding or hard pruning. If pruned before the soil conditions are improved such trees will die. In other words fur maximum fruit production and a reduction of. Witch's broom it is necessary to be able to read tree language and thereby be able to anticipate cultural requirements.

***Vide* Diagram**



This system will tend to stabilise growth and pod production thereby reducing cost of picking. Furthermore, if the pruning system advocated by one of the writers (5) be adopted for Coffee it is possible that the clashing of the cropping periods of Coffee and Cacao on estates growing both crops might be avoided thus facilitating labour difficulties. This, however, is a matter which requires further investigation before definite statements are possible.

Suggested Methods of Control

I. To continue cutting out diseased parts and destroying them. The methods suggested above for brooms borne on side branches would be a definite improvement over the present method of cutting out at a point some six inches behind the base of the brooms for the reasons already given above.

II. The practice of flaming mushroom-bearing brooms by means of sacking soaked in oil, as done on some estates before cutting down the broom is a very sound practice since it checks the distribution of spores from the mushrooms as they fall and are broken into fragments against the branches of the trees.

III. To give attention to all factors which will bring about improvement in the condition of the Cacao trees. Stress is laid on the necessity for improving soil conditions apart from the direct losses caused by witch broom disease in the form of infected cushions and pods. Black Pod causes much more damage up to the present time. The canker form of this disease also causes immense damage and is one of the main factors which decides the economic age-range of Cacao in Trinidad. A large canker on a limb also causes frequent defoliation. The losses caused by these diseases will be very markedly reduced when the condition of the soil is improved to a point which makes shade reduction possible.

Cacao growing is being extended in other parts of the world where soils have not been exhausted to the extent they have in Trinidad. On the other hand, it will take many years before the knowledge of Cacao growing and preparation reaches in such countries the standard in Trinidad at the present time. It must, however, be recognized that competition is being felt and the only way in which Trinidad Cacao can hold its own and indeed markedly improve its position is by means of more intensive cultivation. By intensive cultivation is not meant necessarily the digging of deeper drains and brushing, since both these operations when done at the wrong time can prove injurious to Cacao. To come within the meaning of " Intensive Cultivation " each operation must result in increased yield. With increased yield and increased quality the high standard of preparation of Cacao in Trinidad as compared with other larger Cacao growing countries will have far greater influence than at the present time.

The problem in Cacao growing is, in the writers' minds, very similar to that which is confronting Coconut planters in Trinidad, except that it is not so difficult in application and is far more likely to yield satisfactory results on a larger scale. In conclusion the writers wish to point out their appreciation of the fact that to know what to do is not the end of the problem. Another problem still remains for a large number of planters, namely, how to do it. In other words it, to a great extent, resolves itself into an economic problem.

Summary

I.—Dormant Buds.

Infection experiments are described which show that buds whilst in a dormant condition are not infected by the fungus *Marasmius perniciosus*. Both terminal and lateral growing points arc attacked with the result that subsequent extension growth takes the form of a Witch broom. The size (i.e., both length and thickness) of the brooms so produced depends on the rate and strength growth after infection. Strong and rapidly growing terminal and side shoots produce long witch brooms which are twice or thrice thicker in diameter than the shoot on which they are borne. Witch brooms which are produced on weak terminal or side shoots are shorter and not markedly swollen, nor is the size of the leaves so markedly reduced.

II.—Sporophore Production.

Laboratory experiments show that the fungus M. perniciosus cannot produce sporophores (mushrooms) on witch brooms when constantly kept in a dry, moist or even saturated atmosphere. In order to bring about conditions conducive to sporophore (mushroom) production the brooms must be subjected to prolonged and frequent wettings with rain or tap water.

III.—Green and Brown Brooms.

The question whether green brooms can form mushrooms is indicated as a most important point for future investigation.

I V.—Weather Conditions.

As wet weather follows dry periods the incidence of Witch broom increases rapidly. This is due to (a) increase in the number of sporophores produced by the fungus in wet weather (6) the flush of growth in the Cacao when wet weather follows a dry period.

V.—Defoliation.

The time, extent and frequency of defoliation in Cacao is of extreme importance in connection with Witch broom disease since six weeks after defoliation the Cacao produces a flush of growth. There are many factors, which influence defoliation in Cacao including (i) Type of soil (ii) Drainage (iii) Windbreaks (iv) Shade(v) Atmospheric humidity (vi) Thrips damage

(vii) Pruning (viii) Type of tree (ix) Position of Cacao in relation to prevailing winds. Each of these factors is discussed.

VIII.—Spraying.

Spraying Cacao trees with two per cent. Bordeaux Mixture makes the leaves a darker green and prolongs the life of the leaves. This means less frequent defoliation and fewer flushes, and therefore partial control of witch broom. Spraying with Bordeaux Mixture is not likely to affect materially the incidence of witch broom disease on account of its direct effect as a fungicide.

Spraying against Witch broom is not recommended because it is expensive, difficult to apply and in the majority of cases the labour and water supply in the dry season are not available to carry it out to any extent. The chief objection to it, however, is that it merely begs the question and tends to cloak over the fundamental and inevitable issue, namely, the improvement of the soil. The writers feel that the money spent on spraying if invested in manure to be applied to the soil would give better and more permanent results.

IX.—Type of Tree.

Adverse conditions for growth have a definite effect on Cacao trees in that the leaves become very much more numerous per unit length of branch and at the same time are very much smaller in size. Coupled with this are the shortening of the internodes and an increase in the number of side branches produced, so that the whole tree has the appearance of a Witches' broom as the term is applied generally to the phenomenon in plants other than Cacao. This means that per unit area of surface above ground the weak tree will have a far greater number of growing points than the good tree and therefore has of necessity an equally greater number of infection points. If adverse conditions are allowed to continue beyond a critical point the number of growing points become gradually reduced until the tree dies.

Acknowledgments

We wish to express our gratitude to all the Officers of the Department of Agriculture of Trinidad and Tobago for their generous co-operation in facilitating the work at all times.

We also wish very sincerely to thank the owners and management of St. Anna Estate for putting a field of Cacao at our disposal without restriction and for their ready help and co-operation at all times.

Bibliography

1. Ballou H. A.— "Observations on Insect Pests in Grenada" *Bull. Entom. Res*. Vol. VI, p. 75. 1915.

2, Briton-Jones, H. R.— "Wilt Diseases of Coconut Palms in Trinidad" Part I, Supplement to *Trop. Agriculture*, May 1928. Part II, Supplement to *Trop. Agriculture*, October, 1929.

3. Briton-Jones, H. R.— "Witch broom disease" *Trop. Agriculture*, VI, 2, p. 57, 1929.

4. Briton-Jones, H. R.— "Witch broom disease" *Trop. Agriculture*, VI, 1, pp. 20-22, 1929.

5. Briton-Jones, H. R.— "Control of the American Leaf Disease (*Omphalia flavida*) on Arabian Coffee in Trinidad." I.C.T.A. *Memoir No. 2., Myco. Series*, August, 1930.

6. Jacquet (J.H.)— "Les balais de sorciere du Cacaoyer et les moyens de les eviter (Witches' broom of Cacao and the means of avoiding it)" — *Agron. Colon*, XVIII. No.137, pp. 129-133, 1929.

7. Freeman, W. G.— "Witch broom in Trinidad" *Trop. Agriculture*, V, No. 11, pp. 287-288,1 fig., 1928. and Freeman, W. G.— "Witch broom disease" *Trop. Agriculture*, VI, 2, pp. 55-56, 1929.

8. Howard, A.— "The fungoid diseases of Cacao in the West Indies." *West Indian Bull.* page 205, 1901.

9. Nowell, W.— "Diseases of crop plants in the Lesser Antilles" West India Committee, 14 Trinity Square, London E.C. 3.

10. Ritzema Bos.— "Die Hexenbesen der Kakaobaume in Surinam" *Zeitschrift Pflanzenkranhheiten*, Bd. XI, 1901, p. 27.

11. Rorer, J. B.— "The Suriname Witch broom disease of Cacao." Board of Agric., Trinidad and Tobago, *Cir*. No. 10, 1913.

12. Stahel (G.)— "*Marasmius perniciosus*, nov. spec." Department van den Landbouw in Suriname, *Bull.* No. 33, September, 1925.

13. Stahel (G)— “Witch broom” *Proc. Agric. Soc.* Trinidad and Tobago, XXIX, No, 1, pp. 12-19, 1929.

14. Steil, F.— “Witch broom disease of Cacao and its Control” *Bull. Dept. of Agric., Trinidad and Tobago,* XXI, No. 3, pp. 3-14, 7 fig., 1928.

15. Van Hall, C.J.J. en Drost, A.W. — “De Krullotenziekte der cacaoboomen in Surinam, haar oorzaak en haar bestrijding.” Dep. von Landbouw in Suriname, *Bull.* No. 16, 1909.

16. Van Hall C. J. J.— Cocoa, 1914, page 257.

17. Went, F. A. F. C. — “De ziekteverschijnselen van de cacao plant in Surinam”, *S’ Gravemhage*. 1903.

18. Went, F. A. F. C.— “Krulloten en versteende vruchten van de cacao in Surinam, verhandelingen der Kou.” *Ahad van Wetenschappen to Amsterdam* 2 Sectie deel X, No. 3, 1904.

19. Went, F. A. F. C.— “Discussion on Witch broom disease” *Proc. Agric. Soc.*, Trinidad and Tobago, XXVIII, 9, pp. 381-390, 1928.

20. Ciferri, (R).—Phytopathological survey of Santo Domingo, 1925-1929.— *journn. Dept. Agric.* Porto Rico, XIV, No. 1, pp. 5.44, 2 Pl., 2 Maps, 1930 . {Rev. App. .Myco. Vul. IX, Pt. 8, pp. 310-512.)

Extracted from Volume 13, Number 10, 1936

STUDIES IN WEST INDIAN SOILS

BY F. HARDY
Imperial College of Tropical Agriculture, Trinidad

Investigations into the origin, classification, properties and agricultural relationships of the soils of the West Indies region have occupied a great deal of the time and facilities of the Chemistry Department of the College since its inception in 1922. Indeed, the earliest attempts to bring together the available information concerning the soils of the West Indies, and to extend our knowledge of their origin and crop relationships within the different insular areas were made before the College was founded, and whilst the Imperial Department of Agriculture was still in existence, with headquarters in Barbados.

(1) The first publication describing West Indian soils was entitled " The Soils of Dominica, their Genesis and Fertility, considered in Relation to Reaction". It formed an article in the now defunct West Indian Bulletin, Vol. XIX, issued in 1922. It was based mainly on geological considerations, and involved a study of soil acidity in its possible bearing on the growth of the cacao crop and the lime crop. In the year 1920, when this investigation was undertaken, colorimetric methods for determining soil reaction by means of the new pH indicators elaborated by Clark and Lubs had only just been perfected. One of the main reasons for studying the soils of Dominica at that period was to apply the new technique and the newer knowledge of the role of acidity in soil fertility to specific crop problems and to questions of soil formation from different kinds of parent rock materials exposed to different amounts of rainfall. The investigation was one of the first of its kind to be initiated within any special area for such purposes, but it cannot be claimed to have been exhaustive, and the soils of Dominica still offer innumerable problems awaiting detailed study.

(2) The second publication concerning West Indian Soils was entitled "The Soils of Montserrat their Natural History and chief Physical Properties, and the Relationship of these to the Problem of Die-Back of Lime Trees". It appeared also in the West Indian Bulletin, Vol. XIX, 1922, pp. 189-213. The chief object of the investigation which forms the topic of this second paper, was to study the environmental conditions associated with the dying-back of twigs of lime trees, and to attempt some explanation of its incidence. The field work was performed in collaboration with the Plant Physiologist of the Imperial Department of Agriculture, Dr. T. G. Mason, later the first Professor of Botany at the College, and now Plant Physiologist to the Cotton Growing Corporation at their Research Station in Trinidad. Mason demonstrated a distinctive difference in the zonation of the young woody tissues of lime trees exhibiting the die-back condition and that of the wood of normal healthy trees. This difference could approximately be correlated with differences in the moisture conditions of the environments of the two contrasted kinds of trees, as decided by topography, protection front drying winds, and physical type of soil which decide its permeability to water. Physical soil-type was further found to be an expression of geological origin, so that the account of the soil aspects of the problem involved a brief discussion of the genesis of the soils of Montserrat. Its main purpose was nevertheless a study in crop ecology.

(3) Between the years 1922 and 1930, the organisation of the Chemistry Department of the College, the preparation of courses of teaching, the study of certain fundamental problems of Soil Physics, and the initiation of researches into the Froghopper problem of sugarcane in Trinidad delayed further the study of West Indian soils along the lines already initiated. Preliminary work on the soils of cacao and forest lands in Trinidad and Tobago conducted during this period (mainly with a view to providing subjects for the dissertations of specialist Post Graduate students of chemistry) eventually culminated, however, in the publication in February 1931, of the first of a new series of " Studies in West Indian Soils", namely, No. III, "The Cacao Soils of Tobago", in which the collaboration of two Post Graduate students, Messrs. C. G. Akhurst and G. Griffith was involved. This publication formed a supplement to the College Journal, Tropical Agriculture, Vol. VIII, 1931. Its general arrangement, scope and method of presentation

0041-3216/2021/030196-202

of field and laboratory data were somewhat novel; they have been retained more or less unchanged up to the present time in succeeding articles or reports, conveniently referred to as “grey-books” on the Soils of the West Indies.

In this new series of soil studies initiated in 1928, a profile method of soil examination has been introduced and developed. Selected sites are explored by digging six-foot pits. The soil section thus exposed generally displays at its base the more or less unaltered parent rock. In many cases, ten-foot pits (such as are favoured by oil geologists in Trinidad) would have been preferable, but they are much more expensive to dig, and more difficult to sample. The profile is marked out into layers differentiated by changes in appearance and other easily discernible features, except where the changes are uniformly graded, in which case, arbitrary subdivision into multiples of three inches is generally made. The surface soil, containing the bulk of the “feeding roots” of crop plants or forest trees, is more minutely subdivided, for example, into layers of the following successive depths : 0-14, 14-3, 3-6, 6-9, 9-12, 12-18 and 18-24 inches, below which the deep subsoil is marked out into foot layers. A single six-foot profile may thus comprise between eight and 12 different layers, each of which is described and sampled separately. Full notes are made at the time of sampling on the more obvious features of the soil, according to a descriptive nomenclature and a simple colour chart that have been evolved for the purpose. The individual soil samples are separately collected, bagged and labelled, and eventually transported to the laboratory, where they are air-dried, pulverised and sifted prior to detailed laboratory study.

The methods of laboratory analysis include both physical and chemical routine determinations. They have been specially selected, exhaustively tested, and sometimes modified in order to render possible the examination of very large numbers of soil samples in a uniform manner, involving a minimum expenditure of time. Progressive counts of the methods finally applied are given in the published reports or articles describing the studies in West Indian Soils since the inception of the soil profile procedure in 1928. By the end of the year 1935, some 38o soil profiles in various parts of the British West Indies region had been dealt with in this manner, including the detailed examination of some 3,30o separate soil samples, and the work is still proceeding. This achievement has been possible mainly because of the existence of exceptionally suitable laboratory facilities provided by the College, and the organisation of a reliable staff of junior laboratory assistants working under the direction of a highly qualified analyst (Mr. G. Rodriguez). The junior staff is recruited mainly from youths of East Indian descent who have previously received an all-round elementary education in the schools of Trinidad.

The chief advantage of the rapid accumulation of a large mass of field and laboratory data lies in the fact that it permits detailed comparisons to be drawn between soils of different origins, formed under different climatic conditions, and subject to differing degrees of alteration through exploitation or utilisation for the growing of various types of agricultural crops. Thus, it has recently been found possible to diagnose with a fair degree of reliability the nutrient conditions of any particular type of soil in relation to the growing of cacao, citrus, banana, arrowroot and sugarcane in the West Indies region. Certain “limits of adequacy” with regards to soil nitrogen, phosphate and potash have been provisionally established for each of these crops, and the information is available for application to regions outside the West Indies. How far the tentative numerical relationships and the diagnostic features of suitable and unsuitable (“good” and “bad”) soils may apply elsewhere, is a subject for future consideration when the methods have been more widely applied. The co-operation of soil chemists working in other tropical countries is being sought, and plans are being suggested for the examination in the College laboratories of representative soil samples imported from remote regions such as West Africa.

In attempting to establish relationships between soil factors and crop productivity, full use is made of yield data and the analysis of yield, such as have been developed for the cacao crop by the College Department of Economics under Professor C. Y. Shephard.

The soil data not only have proved serviceable in the diagnosis of soil conditions; they have also yielded much information concerning the processes of soil formation. The methods differ fundamentally from those employed by other schools of pedology, in that the soil profile is described, not simply as a morphological unit on appearance and structure alone, but mainly in terms of determinable physical and chemical constants. Thus, the laboratory values enable one to describe the texture profile, the reaction profile, the organic matter and nitrogen profile, the soluble salt profile, and the available phosphate and potash profile, as separate, though related, entities. Such physical and chemical descriptions of the soil profile, augmented by special laboratory determinations of exchangeable bases in representative, composite surface soil samples, and by complete chemical analyses of parent rocks, together with, in some cases, that of clay fractions, provide much more reliable information regarding the nature and effects of the processes of soil formation than mere inspection alone. By their employment and application, soil profiles may the more accurately be compared and classified. The numerical data for the successive layers of soil of each profile may be set out in columns of colours on profile charts, which include a column of actual specimens of the soil itself, mixed with transparent varnish and painted on to the cards. A scheme of colours for most of the determined soil constants has been devised for use in the preparation of these profile charts. Sets of completed charts are filed for future reference.

Referring again to the third article of the Studies in West Indian Soils, namely "The Cacao Soils of Tobago", the soil profile data clearly indicated striking differences between "good" and "bad" cacao soils, the accepted definition of " good soil being one which supports mature cacao trees yielding over eight bags (each of 165 lb. weight) of dried caca, beans per r,000 pickets or tree sites. Two chief factors appeared to account for high yielding capacity in the better cacao soils of Tobago, namely, (I) a high nutrient status (as estimated by electrical conductivity of water extracts of soil), and (2) a relatively high ratio of carbon to nitrogen in the organic matter contained in the surface six-inch layer of soil.

At the time when the Tobago cacao soils were being examined, individual determinations of available phosphate and potash had not been introduced into the routine laboratory work, so that the specific nutrient factors of the soil could not then be identified. Later investigations, not yet published, have demonstrated that many of the Tobago soils are very deficient in potash, which seems to be associated with a well-defined leaf symptom, described as "marginal leaf-scorch of cacao". (See Fourth and Fifth Annual Report on Cacao Research for 1934 and i935.) This symptom was first noted by Mr. J. A. McDonald (Chemist for Cacao Research) in 1933, in sand cultures of cacao seedlings treated with a nutrient solution lacking potassium. It has since been observed widespread in the field in various parts of Trinidad and Tobago, particularly on trees growing on soils containing less than a certain critical amount of available potash, as measured by a standard laboratory method. Some of the Tobago cacao soils are also deficient in available phosphate; deficiency in this nutrient seems to diminish the uptake of potash, so that, in certain cases, the effect of these two nutrients appears to be interdependent.

High ratio of carbon to nitrogen indicates an early stage in the decomposition of leaf and root vegetable debris; its association with high yields of cacao was originally noted for the cacao soils of Tobago by Dr. G. Griffith whilst attempting to correlate yield data with various soil factors. The reason for this striking correlation (which has since been conclusively demonstrated for the cacao soils of Grenada and of Trinidad) is difficult to find, but a suggestion that it is directly concerned in the prevalence of *mycorrhiza* in the soil, which is causally connected with the ability of the cacao root system to absorb nourishment from the soil, has received some verification from the work of Mr. E. E. Pyke, published in the Fourth Annual Report on Cacao Research, 1934, pp. 41-48. It is evident from these observations that the study of the cacao soils of Tobago has provided numerous promising lines of investigation, and has educed many suggestive ideas, so that the selection and application of the methods employed therein have been amply justified.

(4) The fourth article of Studies in West Indian Soils concerns the Cacao Soils of Grenada; it was published in December, 1932. The soils of Grenada have been formed from andesitic and basaltic lavas, and from their pyroclastic or fragmental equivalents (agglomerates and tuffs), though many of them belong to the river alluvial type, derived from the same volcanic parent materials. They are therefore somewhat different from the soils of Tobago, which have been formed from a more acidic kind of igneous rock, namely diorite, and from metamorphic rocks (mostly schists) that resemble somewhat the rocks of the Northern Range of Trinidad. Furthermore, the greater altitude and consequently the greater rainfall of the interior lands of Grenada have brought about a greater degree of rock alteration, weathering and leaching than have occurred in Tobago, so that the Grenada soil profiles are generally much more "mature" and more highly stratified, or differentiated into layers, than those of Tobago. Nevertheless, the same features distinguish the "good" cacao soils from the "bad".

The individual soil samples collected in Grenada were all analysed for available phosphate. This additional method of laboratory examination, applied for the first time as a routine procedure, revealed the new fact that phosphate is characteristically deficient in the poorer-yielding cacao soils of Grenada. These poorer soils generally occur at the greater elevations in areas of high rainfall; doubtless intense leaching has here deprived the soil of a large part of its content of phosphate and of lime, and has thus produced highly acidic conditions in the surface layers, as well as a marked deficiency of available phosphate. The chief features differentiating "good" from "bad" cacao soils in Grenada are their higher carbon/nitrogen ratios and their higher contents of available phosphate. These two relationships with yield data have been established by statistical analysis. Other factors, such as deficiency of potash and highly acidic reaction, may also have contributed to the low yielding capacity of some of the poorer upland soils.

(5) The fifth article of the series is entitled "The sugarcane Soils of Antigua". It was published in April 1933. Its scope and main findings differ considerably from those of the preceding studies of cacao soils formed from igneous rock materials. The soils of Antigua are mostly derived from somewhat abnormal kinds of sedimentary rocks, including saline aqueous tuffs and highly calcareous marls and soft limestones. They are characterised by their highly alkaline reaction, due to the facts that either they contain excessive amounts of free calcium carbonate (limestone and marl soils), or they belong to the category of "black alkali soils" (slightly calcareous, saline, sedimentary tuff soils). The dry climate of Antigua (rainfall 40 to 30 inches a year) is conducive to the development and perpetuation of such soil-types, and the problems associated with their successful utilisation, even for the purpose of producing the widely-tolerant sugar-cane crop, are among the most difficult and perplexing that the agriculturist has to face. They require very careful tillage, and the question of their proper manuring needs special consideration, and entails cautious methods of experimental approach. The various aspects of their handling and treatment are now being actively studied in the field by the Agricultural Superintendent (Mr. F. H. S. Warneford), and by a Specialist Research Officer (Mr. C. F. Charter) employed by one of the large Sugar Companies, acting with the advice and guidance of the Adviser in Sugarcane Experiments to the Commissioner of Agriculture (Mr. P. E. Turner). Recently, additional chemical and physical investigations into the peculiar features of the Antiguan soils have been undertaken by the writer, in continuation of the earlier studies described in Part V of the series under consideration. This additional work may be described in a further publication on the Soils of Antigua, to be issued later in the present year (1936), or early in 1937.

(6) The sixth article of the series is entitled " Some Soil-Types of Jamaica". It comprises an account of the origin, formation, classification and agricultural relationships of the main kinds of soil that occur in this large island of the Greater Antilles. It is the outcome of a joint investigation, undertaken in September 1932, by the Agricultural Chemist of the Jamaica Department of Agriculture (Mr. H. H. Croucher) and the Chemistry Department of the Imperial College of Tropical Agriculture. This publication was issued in August, 1933. The soil-types investigated are mainly devoted to the growth of bananas and sugarcane. The field and laboratory data enabled tentative comparisons to be drawn between the soil-types of Jamaica and certain types belonging to well-known world-groups, such as have been defined by Russian and American pedologists. Furthermore, they provided valuable information concerning the climatic and soil requirements of two important tropical crop plants —banana and sugarcane—which has since been employed in attempts to assess and evaluate other soils planted to these crops in other parts of the West Indies region, notably British Honduras and Trinidad.

The agricultural soils of Jamaica may clearly be classified into soils derived from calcareous parent rocks (such as the white limestones that comprise the great interior plateau occupying over four-fifths of the island), and soils derived from non-calcareous rocks (such as the old alluvial deposits that occupy the vast southern coastal plains around Kingston and in the parishes of St. Catharine and Clarendon). Within the regions occupied by these two geological subdivisions, the agricultural lands may be further classified into wet lands and dry lands, according to the magnitude of the annual rainfall. Finally, within the wet and the dry districts, the lands may be differentiated into flat lands and hilly lands.

The interplay of the three factors, nature of parent rock, rainfall, and topography, has resulted in the development of several distinctive soil-types, showing natural gradations or intermediate stages, and ranging between very wide extremes. Saline and alkaline dry-land soils, similar to some of those occurring in Antigua described in the last section, represent one extreme, and deep red earths, derived from upland limestones or from ancient basement conglomerates under conditions of high rainfall, represent the other extreme. The multiplicity of environments thus displayed in Jamaica favours great diversification in agricultural cropping, and offers numerous interesting problems, both in pedology and in crop ecology.

(7) The seventh article of Studies in West Indian Soils, namely, "The Cacao Soils of the Montserrat District of Trinidad" (published in October 1933) reverts to a fuller discussion of the inter-relationships between climatic and soil conditions and the growth and reproductivity of the cacao tree. The fact that cacao was planted in Trinidad under a wide range of conditions when prices were high, has furnished valuable material, both for ecological and economic study. Since prices have dropped, greater interest has been shown in the costs of production of cacao, and the quantitative data recently collected have revealed the great importance of the nutrient status of the soil which differs widely for the different soil-types. The main aim of the soil investigation described in publication No. VII, was therefore to establish as closely as possible the relative importance of the soil factors responsible for high yielding capacity, and contrarily, for low yielding capacity for cacao. The distribution of "good" and or "bad" cacao soils, and the full description of soil types falling within these two broad categories, were attempted for some 80 square miles of irregular country comprising the Montserrat District. A detailed soil map of the area was prepared by Mr. J. A. McDonald, and numerous soil samples, representing some 85 different soil profiles, were fully analysed in the laboratory. The results of this detailed investigation amply substantiated those obtained from the earlier study of the Cacao Soils of Tobago (Publication No. III), and more clearly identified the main soil factors associated with high cacao yields. In particular, they further stressed the importance of the nature and amount of the organic matter component of the surface soil, and the total and relative quantities of available phosphate and potash in the soil. An important outcome of the work was the inauguration of a series of specific manurial experiments on cacao as part of the College Cacao Research programme. These field experiments have since been greatly extended by Dr. F. J. Pound, Agronomist of the Trinidad Department of Agriculture, in connection with the new Cacao Relief Scheme, which was launched in 1935. The further exploration of the cacao soils of Trinidad into districts where other well-defined types of soil occur is being actively pursued. Descriptive accounts of the progress made and of any new results which may accrue from these continued investigations will form the topics of future articles of the series.

The cacao soils of Trinidad differ from those of Tobago and Grenada in that they have been derived mainly from sedimentary rocks. Only one very small area of outcropping igneous rock occurs in Trinidad (near Toco on the north-east coast), but its derived soils have not yet been studied in detail. Certain of the sediments contain the mineral gypsum; soils formed from gypseous rocks appear to be very unsuitable for cacao production. Thus, the cacao soils of Trinidad offer a wide range of problems, and it is hoped that their exhaustive study may provide important generalisations which will be of value to cacao growers, not only in the West Indies, but also in other parts of the Tropics.

(8) The next article of Studies in West Indian Soils (No. VIII), published in December 1934, concerned an entirely different set of problems, associated with another kind of tropical crop, whose requirements are very different from those of the crops that had previously been examined. It is entitled "The Agricultural Soils of St. Vincent", and it discusses the soil relationships of the arrowroot plant. This article was published in December 1934, with the collaboration of an ex-student of the College, Mr. C. K. Robinson, now Assistant Superintendent of Agriculture in St. Vincent.

The parent soil-forming rocks of St. Vincent are mostly volcanic agglomerates, loose ash and dust. In this respect they differ from those of the neighbouring island, Grenada, which are mainly compact igneous lavas. Some of the St. Vincent volcanic ash was spread over the northern part of the island during the last eruption of the Soufriere Mountain in 1902 and 1903. Heavy rains have since removed the greater part of the ash accumulations, but at least one-third of the total area of the land still consists of recent volcanic ash, which has not yet been very much altered by weathering agents. The rest of the land area is made up of much older fragmental volcanic rocks, which have been considerably altered and weathered, and often cemented into hard gritty material known locally as "terras". Few lava flows occur in St. Vincent. The kinds of igneous rock comprising both the lavas and the fragmental materials are similar to those occurring in Grenada, namely andesites and basalts, but chemical analysis has revealed the striking fact that the St. Vincent rocks contain significantly lesser amounts of total potash.

The soils of St. Vincent thus differ very materially from those of Grenada described in article No. IV of the Studies in West Indian Soils. Whereas many of the Grenada soils are red or red-brown clays and looms, the soils of St. Vincent are mostly ochre-yellow, brown or black sands, containing little mineral colloidal matter. Evidently rock weathering has proceeded much farther in Grenada than in St. Vincent, a fact which is clearly demonstrated by a microscopical examination of profile samples representative of the different types of soil occurring in the islands. The study of the volcanic ash soils of St. Vincent furnished an excellent opportunity for applying the methods of mineralogical analysis recently advocated by Dr. Vageler in his book "Tropical Soils" (1933), who claims that "the permanence of fertility in a soil varies with its content of minerals which are still liable to decomposition". The mineral analyses were performed by a Post Graduate student of the College (Mr. R. A. Hamilton), who found that the St. Vincent soils consist almost entirely of unaltered fresh mineral grains (soda-lime felspars, hypersthene, augite, magnetite and olivine). On the other hand, the red soils of Grenada contain less than 25 per cent. of unaltered mineral grains, and generally of more than seven per cent., though certain of the sandier ash and tuff soils may contain up to 34 per cent. of fresh grains. Only in very few cases, however would the soils of Grenada be considered to be definitely deficient in fresh minerals, according to the standards suggested by Vageler, but some of them might be regarded as border-line cases, whose degree of permanence of fertility may be low.

The fundamental differences between the soils of St. Vincent and those of Grenada are clearly reflected in the kinds of crops grown, and the types of agriculture practised in the two islands. Whereas cacao is the main crop of Grenada, arrowroot and cotton are the crops chiefly cultivated in St. Vincent. These two crops require a drier habitat than cacao, and well-drained, highly permeable sandy soils, such as abound in St. Vincent, are eminently suited to their moisture requirements, and their methods of planting and reaping, even in districts where the rainfall is high. Chemical analysis has revealed the fact, however, that the St. Vincent soils are not altogether satisfactory with regards to their nutrient status, and critical field manurial experiments have demonstrated that nitrogen and potash are the chief nutrients that are generally deficient, both in arrowroot and in cotton fields; where potash is abundant, additional nitrogen can he utilised with benefit to the crop. A useful rough index of soil suitability is furnished by the potash/nitrogen ratio of the soil. The production of abnormal arrowroot rhizomes ("cigar roots") also appears to be associated in some manner with unsatisfactory nitrogen and potash supplies in the soil, not only with regard to the total amounts of these nutrients, but also with regards to their ratio-balance or proportionate amounts. Organic matter has long been suspected of exercising a particularly important role in the fertility and productivity of the soils of the cotton and arrowroot lands of St. Vincent; organic mulches have frequently given very large increases in crop yields. A critical study of this question, based on laboratory data and field experimental results, has indicated that the main effect of organic manure is nutritional, due to its high content of nitrogen, although a possible solubilising effect on the soil minerals of carbonic acid, produced by its oxidation in the soil, may increase the availability of their potash and phosphate contents.

(9) The ninth article of the series describes "Some Soil-Types of British Honduras, Central America", and was published in December 1935. It was the outcome of an arrangement between the Government of British Honduras and the Principal of the College, whereby a reconnaissance survey of the chief soils of the Colony should be made with a view to deciding their suitability for the continuation and possible extension of banana, grapefruit and sugar-cane cultivations. The investigation afforded an opportunity of testing some of the conclusions reached in former studies with regards to the ecological equirements of these three important tropical crops. The field work was undertaken with the co-operation of Mr. H. P. Smart, Agricultural Officer of British Honduras, and of Messrs. J. B. Kinloch and R. S. Pelly, Forestry Officers. The lands of British Honduras are mainly undeveloped.

Less than seven per cent. of the total area of British Honduras is occupied by existing or recently-abandoned cultivations, whilst more than 50 per cent. is covered by tropical rain forests which occupy most of the interior lands. The rest of the area (43 per cent.) comprises swamp forests of the coastal and riverain strips, wet and dry savannahs, and intermediate lands.

The chief agricultural soils occur on river alluvial lands, such as those within the Stann Creek Valley which were once famous for commercial banana production until Panama Disease devastated the cultivations. The Stann Creek area has been recently reopened for peasants' settlement, and several flourishing grapefruit plantations have replaced many of the former banana fields. The soils are variable and generally highly acidic, but their nitrogen and potash contents are high, though their phosphate content is low. The laboratory data obtained for these soils have suggested lines for field experimentation with a view to formulating suitable manurial treatments. Comparisons with data for other banana and grapefruit soils occurring elsewhere in the West Indies region have proved very useful in assessing the nutrient status of the Stann Creek alluvial soils.

The greater part of British Honduras is covered with black and red soils derived from soft marls and hard Tertiary limestones. These calcareous deposits form flat plain country of low relief,extending far northwards into Yucatan. Most of the land is closely afforested and abounds with relics of the ancient Maya civilisation, such as terraces and mounds. Around Corozal, in the extreme north of the Colony, occurs a deep, rich, black marly soil which grows magnificent sugar cane crops, but a sugar industry has not yet been developed and centralised there, though plans are now being advanced for the erection of a large sugar factory, which should greatly encourage the development of the Corozal district. Other parts of the marl and limestone region, within access by road of Belize (for example, the Boston District) may soon be planted in bananas. The soil is neutral or alkaline and quite fertile, but it is frequently underlain at shallow depths by flints or hard limestone which seriously restrict the root room.

The southern part of British Honduras experiences very high annual rainfall (over 100 inches). Certain of the alluvial soils bordering the more navigable rivers are partly developed for agriculture, but the greatest expanse of productive land occurs around Punta Gorda (Toledo District), which was originally settled by Americans after the Civil War in the United States. The soil is derived from Miocene sediments of variable composition, including some that are highly calcareous. Many of the soils are quite fertile, though somewhat lacking in potash. They support fair crops of sugar cane, but they would require special treatment to enable them to produce profitable bananas. Hill rice is being grown in certain parts of the district, and a rice experimental station has recently been established near Punta Gorda.

The forests of British Honduras have been classified into different associations dominated by distinctive tree species, certain of which, such as mahogany, have considerable commercial value. The chief factors which appear to have affected the distribution of the forest types are rainfall, topography, kind of soil, and interference by man. The chief controlling agency is probably soil water supply, whose magnitude depends on the interaction of these factors, and particularly on the physical properties of the soil, which differ significantly between porous sands, impervious acidic clays and permeable calcareous clays or marls, all of which are represented among the soils of British Honduras.

It is evident from this summary of some of the main findings of these studies that a very wide range of problems is presented to the scientific investigator of the soils of the West Indies region. The climate varies widely in different parts of the legion and within each insular area or country. The soil-forming rocks include almost every main type known to the geologist. Every stage of agricultural development is represented, ranging from forest exploitation, shifting cultivation and peasant settlement to estate organisation, orchard management and intensive gardening. Numerous different kinds of tropical and sub-tropical crops are grown, both herbaceous and arboreal, and many different systems of cultivation are practised, involving hand tillage, implemental tillage, thorough drainage, irrigation, cover cropping and all sorts of manuring. The value of exact field experimentation is gradually being realised, and the need of detailed soil surveys is becoming increasingly experienced as economic conditions and external competition is forcing the agriculturist to learn how to conserve soil fertility, to improve yields, and to diminish costs of production. Since the soil is the basis of all agriculture, the continued investigation of these problems will always demand first attention. The accumulation of such relevant data as can be obtained by reliable methods of field and laboratory research thus requires no justification, and the start that has already been made in the study of West Indian soils should lead the way to their fuller understanding.

Extracted from Volume 18, Number 12, 1941

PROGRESS IN CONTRIBUTING COLONIES OF SEEDLINGS RELEASED BY THE BRITISH WEST INDIES CENTRAL SUGAR-CANE BREEDING STATION

By *A. E. S. McIntosh*
(Geneticist)

Introduction

This article is concerned primarily with the commercial results achieved or likely to be achieved by seedlings released from the Station rather than with methods adopted in breeding and selecting. It is, however, considered better for a clearer understanding to give a brief outline of the routine adopted in selection for and despatch to the several contributing colonies.

Seedlings of purely noble-cane (*Saccharum officinarum*) derivation which are selected in Barbados at the end of their second season of test are multiplied for further tests in Barbados and, at the same time, sent to the Plant Quarantine Station in Trinidad for quarantine prior to liberation to the other colonies. Seedlings of such derivation are expected to be of use only in fertile soils where mosaic disease is absent or at least controllable. Such conditions exist to a greater or lesser extent in all the colonies served by the Station so that a general distribution is recommended. During the period of quarantine, which lasts approximately eighteen months, a third season of test has taken place in Barbados. With the additional information derived from this more extensive series of tests the Station is able to advise the Plant Quarantine Station whether any of the seedlings sent there after the second test should be discarded. It may happen that some have already been released from quarantine, in which case the advice to discard prior to multiplication is sent direct to the authorities of the receiving colonies. It should be mentioned here that noble cane seedlings released from Barbados to the Plant Quarantine Station have in Barbados already been proved to be resistant to gumming disease (*Bacterium vasculorum*) while their susceptibility to mosaic is taken for granted.

Seedlings of nobliscd derivation, i.e., derived from at least two *Saccharum* species, one of which is *Saccharum officinarum* are also sent to the Plant Quarantine Station after selection in their second year test. All, however, are not further tested in Barbados since many are not considered suited to Barbados conditions. Selections among second season test nobilised seedlings are for three broad categories, i.e. (1) general purposes, i.e. seedlings considered suited to at least a wider range of soil conditions than seedlings of purely noble cane derivation, (2) intrinsically infertile conditions, i.e. seedlings considered of a hardy nature and (3), areas where mosaic disease is dominant on susceptible varieties and require seedlings with commercial resistance to the disease: this includes both fertile and infertile cane growing areas. Categories (2) and (3) do not occur in Barbados and seedlings selected for them are not as a rule further tested in Barbados except they indicate suitability to Barbados conditions. Thus, the number of seedlings of nobilised derivation sent to the Plant Quarantine Station is always greater than that retained for further test in Barbados. As with seedlings of noble-cane derivation, so with the nobilisations further tested in Barbados, information after the third season's test can be given the Plant Quarantine Station or the receiving colony as to discarding prior to liberation or multiplication espectively.

Despatch of Seedlings from the Cane Breeding Station

The Station was started in 1932. The contributing colonies are Barbados, Trinidad, Jamaica, the Windward and Leeward Islands. The first consignment of seedlings was sent in November, 1934, and one or two lots have been sent each year since. For convenience in presentation these are classified into seedlings of (1) noble and (2) nobilised derivation.

0041-3216/2021/030203-209

(1) SEEDLINGS OF NOBLE CANE DERIVATION.

To date, forty-three of this class have been despatched to the Plant Quarantine Station. The majority of these has been discarded prior to field testing as a result of information derived in subsequent tests in Barbados or in view of obviously better—more especially nobilised— seedlings following them in the selection series. The best of this forty-three are :—B.2935, B.3o13, B.3127, B.3439. Details about each are given later in this article.

The nobilisation work started in Barbados in 1928 has reached the point of producing seedlings appreciably superior to purely noble-cane derivatives. Purely noble-cane breeding was therefore topped in 1940 and it is unlikely that any noble cane seedling released subsequent to the B.34 series will become a commercial variety.

(2) NOBILISED SEEDLINGS

These are derivatives of crossing wild species with the noble species *Saccharum officinarum* and back crossing progeny to noble species. Actually, the degree of back-crossing varies and further, crossing has been effected between derivatives of nobilisation of different species. All resulting seedlings are, however, for convenience referred to here as nobilised seedlings. In all, eighty nobilised seedlings comprising selections from the B.29 to the B.39 series inclusive have been sent to the Plant Quarantine Station. Of this eighty, twenty-eight were sent to Jamaica only with a view to obtaining mosaic disease resistance data, twenty-one of hardy appearance were sent to colonies which include in their cane growing areas, areas of poorer soil, i.e. Trinidad, Jamaica and Antigua, while thirty-one considered to be general purpose types were sent to all colonies. Jamaica has thus received the greatest number of seedlings: this in view of being the only contributing colony where areas exist in which mosaic disease on susceptible varieties is uncontrollable. Such areas occur in both fertile and infertile soils so that both thicker cane and also hardy types resistant to mosaic are necessary.

All seedlings received by Jamaica have been tested for reaction to mosaic disease. This has served (1) to give some idea of reaction by seedlings to the disease in Jamaica as compared with reactions in Barbados (2) to indicate mosaic resistance inheritance trends with a view to guiding future breeding work for Jamaica, and (3) to ascertain the degree of resistance shown by individual seedlings with a view to allocating each to field trials.

It has already been found that reactions to mosaic in Jamaica are different to those in Barbados and this is probably due to the existence of different strains of the virus in the two colonies. It follows that mosaic disease resistance tests in Barbados will not serve for Jamaica and information on mosaic disease resistance inheritance will have to be derived from Jamaica.

At present, in the absence of sufficient data on mosaic disease resistance inheritance, selections for resistance are based purely on the parentage of the seedlings. With the accumulation of data in Jamaica from the seedlings despatched, this selection should in future become more effective.

In general it may be stated that in Jamaica the majority of the seedlings sent has proved susceptible to mosaic disease. It is to be admitted, however, that the tests so far conducted in Jamaica were situated in an area where mosaic disease is especially virulent and that the results of these tests need not necessarily and indeed, are not likely to be an indication of reaction to mosaic in the majority of the cane growing areas in Jamaica. To meet this situation, a new scheme of testing seedling resistances is to be put into effect whereby all seedlings showing sufficient growth promise in the early multiplication stage (which is being done in an area of light mosaic infestation) will be further multiplied and observed in areas representative of the entire Jamaican sugar-cane growing areas. During this stage of multiplication and observation, reactions to mosaic disease will be noted. It is felt that many of the seedlings already condemned for susceptibility to mosaic under the pre-existing conditions of severe test will survive as showing appreciable commercial resistance to the disease in the majority of the cane areas in Jamaica.

Progress with Seedlings in the Contributing Colonies

Since the period of quarantine lasts about eighteen months and the colonies, on receipt of quarantined material, have to multiply the limited amount of planting material received, it follows that Barbados is ahead in the testing programme by at least two years. Thus, for more recent seedlings, conclusive data for Barbados only is available. With the experience gained in the performances of seedlings of previous consignments, both in and out of Barbados, it is possible to forecast reasonably accurately from the data derived in Barbados for these recent seedlings how they will perform elsewhere. Accordingly, performances of seedlings will be considered under three heads, i.e. (1) seedlings which have been tested in field trials in all colonies and for which definite conclusions on commercial value may be made (2) seedlings so far tested extensively in Barbados only and for which some forecasts as to their usefulness to other colonies may be made and (3) outstanding seedlings of more recent origin than those in (2) which are expected to do well in all colonies.

SEEDLINGS EXTENSIVELY TESTED

Under this head it should be noted that seedlings of the series B.29 to B.34 inclusive only have been well tested. This includes both noble and nobilised seedlings which, after their quarantine period, have been recommended for test by the Station. Thus, of the thirty-two noble and sixteen nobilised seedlings originally sent, seven and six respectively only were recommended for field test. The outstanding seedlings in the tests proved to be—B.2935, B.3439, B.34104, and to a lesser extent B.3013, B.3127, B.3254, B. 3172,B.34110. These are described here, special emphasis being placed on the first three.

B.2935

This is a noble cane seedling, its parentage being Ba. 11569 and Ba.6032.It germinates rapidly, bunches quickly and tillers reasonably well, cane growth is fast, arrowing scanty or absent, trashes well with a fair fall of trash; canes are long and thick with average number in the stool: ratoons well only in good ratooning soils: easily milled, low megasse yield and poor burning properties, juice quality average.

Susceptible to mosaic and root diseases, resistant to gumming disease. Suited to good soils only in lower rainfall areas, where it gives high yields of plant and ratoon cane.

In Barbados this seedling entirely supplanted the low rainfall area standard variety—Ba.11569 and in 1940 occupied over 40 percent. of the cane growing area. It was largely responsible for the recent increased sugar crop in the Island. In St. Kitts it eliminated S.C.12/4 and Ba.11569 in the lower rainfall areas and came to occupy over 50 percent. of the sugar-cane area. In Antigua, it eliminated B.4507 in the better drained low-rainfall limestone soils (about 20 percent of the cane area) although Ba.11569 held its place against it in limestone soils with poorer drainage and liable to encourage root diseases. In Trinidad it has little value under the generally prevailing conditions of high rainfall and heavy soils while it Jamaica its susceptibility to mosaic debars it from serious consideration, B.2935 will almost certainly be replaced by B.3439 and B.34104 While the latter in some areas will probably be replaced by B.37161 and B.35245.

B.3439.

This also is a noble cane seedling, its parentage being Ba.11569 (Queensland) 813.

It germinates readily, bunches early and heavily, cane growth is fast, canes are many in the stool and medium width, arrowing intensity is variable, from very heavy to complete absence, trashes well and gives exceptionally heavy fall of trash, canes keep very sound during crop. Ratooning in general very good, although occasionally patchy ratoon springs may be seen: milling and juice qualities in general excellent.

Resistant to root and gumming diseases, reaction to mosaic variable.This is probably the best general purpose noble cane ever produced in Barbados although curiously enough it is less suited to Barbados itself than to the other contributing colonies.

In Barbados its performance relative to other varieties is entirely dependent on the season. In a season of early and prolonged rainfall practically every cane arrows. (It is to be noted that conditions in Barbados are more favourable to arrowing than anywhere else in the West Indies). This intense arrowing precludes any increase in tonnage from late growth. Although juice qualities are excellent, tonnages are not so good relative to the other scanty arrowing types. In average and more especially below average rainfall years, arrowing is much less marked and growth is prolonged throughout the season. Under these circumstances, B.3439 gives relatively high cane yields. It is at all times a good ratooning cane. In Barbados it is susceptible to mosaic disease.

In Antigua it has performed exceptionally well and consistently in tests carried out under widely different soil and rainfall conditions, and it is safe to say that for some years at least it will function as the chief standard commercial variety, replacing both B.2935 and Ba.11569.

In St. Kitts it appears to be definitely superior to B.2935 in cane yield, juice quality, soundness during crop and fall of trash. It is probable that it will be grown to the exclusion of the latter and may also encroach on part of the B.H. 10 (12) acreage.

In Trinidad, according to Turner's Summary of Results of Varietal Experiments, 1941, it has outyielded the standard B.H.10 (12) on five types of clay soils and on the so-called Washington series and also the standards Co.213 and Uba on comparatively infertile soils of the Usine Ste. Madeleine. The latter is a striking proof of its wide range in adaptability.

In Trinidad, where weeding costs are high, the habit of B.3439 of closing in rapidly as opposed to the slow closing in of B.H.10 (12) is a further advantage. It is probable that B.3439 will come to occupy a large percentage of the sugar-cane growing area in Trinidad.

In Jamaica, it is showing a high degree of resistance to mosaic, a surprising feature for a noble cane. Results of its reaping in field trials are available only for the 1940 crop. Here, it was reaped at four places, as plant canes. At all places, it emphatically outyielded the standard, B.H.10 (12), in sugar yields per acre. With these superior yields as plant canes and the high degree of resistance to mosaic and provided it ratoons well, B.3439 is certain to be grown on a large scale in Jamaica, displacing both B.H.10 (12) and P.O.J.2878 and may even succeed under the difficult soil and climatic conditions of the Trelawney cane areas.

Certainly, no noble cane produced in Barbados has had such a wide range of adaptability, from good soils of high and low rainfall to infertile soils, and areas where mosaic disease is virulent. Its commercial exploitation has only begun, but already it seems evident that it will soon be the major variety in the British West Indies.

B.34104.

This is a nobilisation, its parentage being Co.281 x B.H.10 (12). The second season's test from which it was selected was reaped in Barbados on the 7th of February, 1936, that is to say, very early in the crop period. The standard was B.2935 and results from B.2935 and B.34104 were as follows :—

	Canes Tons per acre	Sucrose percent in juice	Average number canes per plot
B.2935	34	15.35	105
B.34104	38	19.70	198

Thus the cane yield was somewhat better than the standard and the juice quality exceptionally high. It is to be noted that the individual canes are much lighter than the standard. Indeed, it is a medium-thin cane type and, at that time in Barbados, there was a decided prejudice against thin-cane types. Accordingly, it was despatched to the Plant Quarantine Station and recommended for release as a hardy type to Trinidad, Antigua and Jamaica. At the same time, in Barbados it was planted in the breeding plots to serve as a future parent plant.

Its performance in the colonies to which it was originally recommended for test has been so striking that it has now been sent to all colonies and in Barbados is now in a comprehensive series of tests. This is a good example of a thin-cane hardy type of seemingly general adaptability. The description is as follows:—

Germination excellent, tillering early and profuse, growth at first slower, but later, when tillering slows down, becomes fast, canes medium-thin, well above average number per stool, leaves form a dense canopy and weed growth suppressed, trashing excellent and very high fall of trash, leaves and leaf sheaths almost devoid of prickles and hairs which, with its good trashing, makes it easily cut and handled, arrowing variable from rather heavy (higher elevations in Barbados) to complete absence (parts of Trinidad) ; cane yields always high, ratooning excellent : milling quality very good, juice quality possibly the best of any Barbados seedling in commercial planting.

In Barbados, so far resistant to mosaic, gumming and root diseases, —in Jamaica, highly susceptible to mosaic, in Barbados, shows resistance to moth borer attack.

In Barbados, extensive results from trials will not be available until the 1942 crop but it is felt that it will suffer from lack of moisture in the lower rainfall areas (a phenomenon especially noticeable in early heavy tillering types) and from marked arrowing in the higher rainfall areas. In the former areas it is unlikely to equal B.37161 and in the latter it is doubtful if it will equal B.35245, B.35187 and B.37161. At best, the writer anticipates that it might have a limited use as an early cane throughout the island, thus displacing B.3439. For Jamaica, the results of the 1941 trials, in which B.34104 appears, are not yet to hand, but on the writer's visit at the end of 1940, it was quite obvious that in growth, B.34104 was outstanding, its only rival being B.3439. The situation, however, is complicated by the fact that B.34104 shows high susceptibility to mosaic in Jamaica. (Parenthetically, its susceptibility in Jamaica should be compared with its resistance in Barbados and the reverse reactions by B.3439 to the disease in both colonies may be noted). Recent information tends to indicate for Jamaica that its susceptibility SCUMS to be associated with a high tolerance, but further conclusive information is awaited. At the moment, it might seem that in Jamaica B.34104 could serve as an early cane in both fertile and infertile areas where mosaic is not so virulent, B.3439 serving as the main crop cane in such areas and as the general standard in severe mosaic areas.

In Trinidad and Antigua, B.34104 has been fairly well tested. In Trinidad, unfortunately it has been directly compared with B.3439 on Ste. Madeleine clay only. Here, in one trial both varieties gave higher sugar yields than. the standards, while in the other B.34104 outpelded the standard Co.213 with B.3439 closely following. Actually, there was little to choose between B.3439 and B.34104. In other trials (1941 series)in which it was tested and in which B.3439 did not appear, B.34104 was superior to all other varieties tested including the standards--B.H.10 (12) and Co.213.

In Antigua, the situation is somewhat similar. That is to say, B.34104 and B.3439 rarely appear in the same trials, although each is superior in their own set of trials. They do appear together in two trials, in one of which there is nothing to choose between them although both are better than the standard Ba.11569, and in the other B.3439 outyields B.34104 and both outyield the standard--Ba.I1569.

It would appear conclusive that both B.3439 and B.34104 are superior to standards and other seedlings tested over a wide range of soil and rainfall conditions, but no conclusive evidence is yet to hand to indicate which is better than the other and under what soil and rainfall conditions. Further experimental evidence is required to settle these doubts and in Trinidad, for the 1940/42 trials, no fewer than fourteen include both seedlings in addition to standards and other seedlings, and for the 1941/43 series nineteen trials are designed to include among others these two seedlings. A similar policy has been adopted in Antigua.

Of the less important seedlings under this head, B.3013 and B.3127 are both noble-canes which between them occupy about 10 percent. of the cane growing acreage in Barbados. Both the been tested in Trinidad, St. Kitts and Antigua but, while B.3013 has shown some promise, it is inferior to B.3439. B.3127 has been disappointing. Both B.3013 and B.3127 are being replaced in Barbados by later seedlings while neither will become commercial canes in the other islands. The seedlings, B.3254, B.3172 and B.34110 are all nobilisations of Java glagah (*Saccharum spontaneum*). In Jamaica, they have shown high resistance to mosaic disease and otherwise reasonably promising growth. They are being tested in variety trials.

SEEDLINGS SO FAR EXTENSIVELY TESTED IN BARBADOS ONLY

This second head concerns seedlings which have so far been extensively tested in Barbados only. The findings from these tests are given here and an attempt is made to give some indication as to the possible usefulness of the outstanding seedlings to the other colonies.

This head comprises seedlings of the B.35 and B.37 series. On account of a change in the technique of testing first year seedlings a delay of one year was involved, resulting in there being no first year seedlings reaped in 1936 and therefore no B.36 series. Nineteen noble cane seedlings and twenty-nine nobilisations of the B.35 and B.37 series were despatched to the Plant Quarantine Station.

Of this number all noble cane seedlings and ten nobilisations were further tested in Barbados.

The others will be further tested in Jamaica, Trinidad and Antigua.These tests indicated that, while some of the noble cane seedlings gave promise of competing with the then existing standards — B.2935,

B.726, B.H.10 (12), B.3013, none had any chance of equalling, let alone bettering the nobilisations which have since emphatically outyielded these standards. It is extremely improbable that any noble cane seedlings of the B.35 or B.37 series will become commercial varieties in the contributing colonies.

Of the nobilisations tested, the following are outstanding—B.35187, B.35245, B.37161. These are described here.

B. 35187.

Its derivation in Barbados is as follows:—

P.O. J. 2725 X B.H. 10(12)

B.3172 X B.39I

B.35187

Germination is excellent, growth habit at first recumbent, later semi-erect, tillering fairly heavy, cane growth with adequate moisture rapid but severely retarded where moisture is not adequate, canes above average in the stool and very thick and long; no arrowing, cane keeping quality very good; ratooning very strong, cane yields in heavier soils with higher rainfall very high: juice late in reaching its optimum but very high quality when ripe.

In Barbados no case of mosaic seen in spite of full exposure to the disease in test plots and commercial plantings, immune to gumming disease and resistant to root diseases.

This variety is suited as a late cane to high rainfall and to a lesser extent intermediate rainfall areas and as a late cane in valley soils. It must have a long favourable growing season to give its high tonnages and ripen its juice. In Barbados, it is being recommended to displace B.H.10 (12) in red soil areas.

Outside Barbados, it is doubtful, on account of late ripening, if it will be of any use in Trinidad except as a late cane in the black marl soils of the Usine Ste. Madeleine. In Jamaica, if it shows commercial resistance to mosaic disease, it should serve as a late cane in good soil areas throughout and replace partly B.H.10 (12) and, with B.3439, P.0.12878 in mosaic areas. In St. Kitts it should be tested as a late cane against B.H.10 (12) in high rainfall areas and in Antigua it should be tested in better class soils as a late cane throughout the island.

B.35245

Its parentage is as follows :--Ba.11569 X P.0.1234. Germination very good, stooling and growth at first slow, later rapid; growth habit upright; canes very thick and long, arrowing scanty or absent, canes keep well during crop; ratooning exceptionally strong: cane yields especially ratoon yields very high in intermediate and high rainfall areas : juice quality excellent early in crop.

In Barbados, highly susceptible to mosaic disease and slightly susceptible to the leaf form of gumming disease, resistant to root diseases.

It is recommended in Barbados for commercial planting to replace B.726 i.e. as an early variety in the high and intermediate rainfall districts.

Outside of Barbados, it is expected that its marked susceptibility to mosaic will exclude it from Jamaica. In Trinidad and Antigua it should be tested under all soil conditions. In St. Kitts it should be tested in the intermediate and higher rainfall areas.

B.37161.

Its derivation in Barbados is as follows:—

P.O. J. 2379 x B.H. I0(I2)

B.3365 x B. 603

B. 37161

Germination excellent, tillering at first very slow and the bulk of the crop made up of mid and late season canes, cane growth exceptionally fast, canes medium to thick, arrowing rather marked at higher elevations, canes keep very well during crop: cane yields under all conditions exceptionally high, ratooning strong; juice purities very high early and throughout crop although brixes only average.

In Barbados so far resistant to mosaic and immune to gumming disease, resistant to root diseases: susceptible to small moth borer although damage does not tend to spread from larval channels in the canes.

This seedling has given outstanding yields under all conditions in Barbados outyielding the standards by 20 percent. to 8o percent. in sugar yields. It seems to have a special preference for heavy soils but can successfully withstand long periods of drought.

Outside of Barbados it should be tested in all colonies under all ecological conditions, but its usefulness in Jamaica will depend on how it reacts to mosaic disease and in Trinidad on how far it can compete with weed growth in the early stages of its growth when it tillers very slowly. Certainly, in Barbados its yields are sensational and it is certain to do well in Antigua and St. Kitts.

Before leaving this section there is one seedling -B.37193--which was despatched to the Plant Quarantine Station but in Barbados reserved only as a parent for breeding and distributed as a fodder cane. Its parentage is the same as B.37161. In the breeding plots and when grown as a fodder cane, it looked so well that it has since been multiplied in Barbados for inclusion in more extensive trials during season 1941/43. In its only test in Barbados, the second year test with B.2935 as standard reaped in 1939, it gave approximately similar cane yields as B.2935 with appreciably better brix. It is a thin to medium width cane but is unusual in that it does not arrow, even in the breeding plots. It is possible that it may serve as a general purpose cane and it is recommended for tests in all ecological areas in the contributing colonies.

OUTSTANDING SEEDLINGS OF RECENT ORIGIN

Under this third head, brief reference is made to those among the seedlings of the B.38'and B.39 series despatched to the Plant Quarantine Station which were outstanding in the second season of test in Barbados.

In the B.38 series, fifteen nobilisations only were sent to the Plant Quarantine Station. The best of those in Barbados were-B.38209, B.38192, B.38233. The first noted was in the thick cane trial with B.2935 as standard, the two others were in the thin cane trial with Co.213 as standard. Their performances are noted in Table 1. These three seedlings should be given special attention in multiplication and testing.

In the B.39 series twenty seedlings were selected and despatched to the Plant Quarantine Station and all are nobilisations.

Of this lot the outstandirg seedling is B.39200, which, in its second season of test was compared with the standard B.2935. (See Table 2.)

This seedling, on account of an early tillering and squat habit of growth covers in early and for this reason, in addition to its good cane yield and juice quality and the fact that it has Co.213 in its parentage, promises to do well over a wide range of conditions.

Several other seedlings of this series did well in Barbados but none was so outstanding as the

above.

Future Policy

In future no more noble cane seedlings will be despatched for the simple reason that they are not so good as the nobilised seedlings.

Further, it seems that the second season's test in Barbados gives a reasonably accurate indicacation of the general value of seedlings for all contributing colonies so that in future, selection standards will be more strict with a likelihood of smaller numbers of seedlings being despatched. The exception at the moment to this policy is of course selection of seedlings for resistance to mosaic to serve Jamaica. Large numbers under this head will still be sent to give information on mosaic disease inheritance trends for Jamaica conditions in addition to increasing the chances of getting individual seedlings with mosaic resistance and otherwise good commercial characteristics.

Table 1.-Thick Cane Trial Reaped February, 1940.

Variety	Derivation	Yield. Tons per acre	Average No. Canes per plot	Per cent. Of Canes Arrowing	Juice Brix
B.2935		20.4	77	0	20.2
B.38209	Ba.11569 X B.34116	24.6	106	0	21.5
	B.34116 = Co.281 X B.H.10(12)				
Thin Cane Trial : Reaped February 1940					
Co.213		30.5	210	45	19.0
B.38192	MD.47 X Co.281	35.9	190	28	21.2
	(MD.47 = P.O.J. 2364 X B.606)				
B.38233	P.O.J. 213 X P.O.J.2878	41.8	193	10	21.2

Table 2.

Variety	Derivation	Yield. Tons per acre	Average No. Canes per plot	Per cent. Of Canes Arrowing	Juice Brix
B.2935		24.5	103	0	20.4
B.39200	B.35206 X B.603				
	(B.35206 = Co.213 X B.391)	31.0	130	4	22.1

Extracted from Volume 26, Number 2, 1949

BANANA RESEARCH AT I.C.T.A.

BY *E. E. CHEESMAN*
(Formerly Professor of Botany at the Imperial College of Tropical Agriculture)

Introduction

This is a review of botanical researches on bananas carried out at the Imperial College of Tropical Agricultfire from 1922 to 1946, and of the present programme. Various findings have been published from time to time in scientific papers, where they are available to the few botanists who are interested in the intricacies of reproduction and heredity in *Musa*. The object here is not to report any new discoveries, but to give an account of the work as a whole that may be of some interest to a wider circle; and the approach is therefore as untechnical as it can be made, having regard to the highly technical nature of the subject. If apology is needed for repetition of some facts about the earlier work that have already been published more than once, it must be pleaded that the last comprehensive review appeared in 1934, and many readers are likely to find it more convenient to have the historical background redrawn than to be obliged to refer back to earlier publications.

As the paper is essentially a progress report of the Department of Botany, and not a review of banana breeding in general, there is little reference herein to the extensive work that has been carried out concurrently by the Jamaica Department of Agriculture. The omission in no sense implies neglect. On the contrary, the two programmes in Jamaica and Trinidad have been carried on co-operatively, have influenced each other in many ways, and have produced broadly complementary results. To a lesser extent, but still materially, the genetical programme has been influenced by other lines of banana research, especially the investigations into Banana Wilt and into fruit storage and transport pursued by other departments of the College, but those also fall outside the scope of this summary.

The Development of The Programme

The first systematic attempts ever made at breeding new varieties of bananas were begun by the College at its inception in 1922. Their immediate aim, was to produce a new export banana resistant to Banana Wilt (Panama Disease), which was causing grave concern by its ravages on the established Gros Michel variety in Jamaica and elsewhere. The inspiration of the work was largely drawn from the success that had attended the raising of new sugar canes from seed in the thirty years preceding. The amount of useful information available was very slender, and it can now be said without the slightest disrespect that nobody concerned had any conception of the magnitude of the task undertaken. Not only was specific information lacking about the genetics of bananas, but knowledge of a more general kind about genetic systems in plants, and particularly about the cytogenetics of sterility, was rudimentary by comparison with what it is today. In these circumstances the programme opened with investigation of the possibilities of producing seeds in the few edible banana varieties available, whilst efforts were made to get together a collection of varieties for more extensive survey. Evidence was soon found that no good results were likely to be had from crosses between edible banana varieties alone; but there happened to be two species of *Musa* in the botanical gardens in Port-of-Spain with inedible fully seeded fruits, and from pollinations by one of these (later identified as a form of *M. acuminata* Colla) seeds were obtained in Gros Michel fruit at a rate of about one per bunch. A few of these seeds germinated, and the first artificially produced hybrid banana flowered in March 1925.

This first hybrid (I.C. 1) showed a closer resemblance to a commercial banana than might have been expected, considering the characters of its male parent. It was, in fact, an edible banana as good in all its characters as several that are in cultivation, but showed certain defects that unfitted it for the export trade. Compared with the standard Gros Michel it had a rather less symmetrical bunch, a slightly lower number of "hands" and a shorter fruit, and it also showed a tendency to produce occasional seeds. All these shortcomings were quantitatively small, and when I.C. 1 proved to be highly resistant to Panama disease, it gave rise to

0041-3216/2021/030210-217

hopes that the whole problem might be fairly easily solved. The next step was to repeat the cross on a large scale in the hope that among a large enough number of seedlings the desired type might occur. At the same time I.C. 1 after bulking up could (as it produced fairly abundant pollen) be self-fertilized, back-crossed with its parents, and used as a male parent on other edible varieties.

Such then was the programme in its second phase, but hopes were not realized. Repetition of the cross gave a series of Fl hybrids which vai ie,1 little from the first example. Some were susceptible to Wilt, and some were in other ways inferior to I.C. 1. One plant (I.C. 2) seemed a little nearer the desired type, especially in being less liable to produce seeds on selfing, and this was released for commercial trials in 1932.

By that time it had become apparent that attainment of the ideal was going to be a long task, and that an interim solution of the problem might be better than none, but I.C. 2 was not regarded as more than that.

Attempts to carry the breeding into later generations gave even less favourable results. Seeds were not readily obtained by selfing or intercrossing Fl plants, and the few F2 seedlings raised all proved inferior to their parents. Backcrossing the Fl to Gros Michel, which was expected to give the best results, was a failure; and backcrossing to the male parent gave, as was expected, plants much inferior to the F1.

These results were partially explained by cytological studies, which were added to the programme as soon as I.C. 1 flowered. It had been realized from the start that in a crop as sterile as the banana there must be irregularity in the reproductive mechanism, and that cytological information would be useful. Examination revealed differences in chromosome number between the parents and the hybrids showing that polyploidy was involved.

The original cross had been between a triploid (Gros Michel) and a diploid (*M. acuminata*) and had produced a tetraploid (I.C. 1). Much later, after examination of a wide range of material, it was found possible to generalize the situation as follows :

1. The basic chromosome number in the section of *Musa* to which the edible bananas belong is x = 11.
2. The fertile species (*M. acuminata*) used in the initial experiments and all others of the same section that have been acquired since are diploids (2n = 22).
3. Most edible bananas are, like Gros Michel, triploid; though a few are diploid
4. All the best of the Fl hybrids obtained from triploid x diploid crosses are, like I.C. 1. tetraploid (2n = 44). Diploids. triploids and aneuploids are also obtained, but none of these approaches as closely as the tetraploids to the characters of a commercial banana.
5. Crossing tetraploids together produces more tetraploids, but these are always inferior to their parents.
6. Crossing triploids with tetraploids (as in the cross Gros Michel x I.C. 1) gives pentaploids and higher polyploids, all of which are commercially worthless.

These generalizations were only arrived at after a great deal of empirical work in what may be regarded as the third phase of the researches. The variety collection was growing steadily, and as the available material increased, a comprehensive programme of cross-pollinations developed. Between 1927 and 1941 the number of inflorescences pollinated was nearly 6,000 and hundreds of seedlings were grown and observed. The policy in this phase was to leave no possible line of attack untried, and even when negative results were obtained, to repeat the cross until the accumulation of failures demonstrated conclusively that it was useless.

In this way the problem was slowly defined and narrowed down by a series of eliminations. The edible varieties were classified into those that give no progeny at all (a class containing some members that would otherwise appear to be very useful material), those that give predominantly diploid or aneuploid progeny of no apparent value for further breeding, and those that give predominantly tetraploid progeny.

From the last class a series of tetraploids was raised by crossing with various fertile diploids, and the teraploids were then crossed together or back-crossed to triploids.

From all this work nothing of direct economic value was obtained, but the effort was not wasted. The workers engaged in it learned thoroughly, as it could be learned in no other way, the behaviour of the diverse material in all types of crosses — diploid with diploid, diploid with triploid, diploid with tetraploid, triploid with tetraploid and tetraploid with tetraploid. They were able to establish beyond doubt that intermediate expression of characters is the rule in *Musa* crosses. The interfertility of the species of *Musa* was found to be surprisingly wide, and even edible bananas sometimes give progeny with species not very closely related to them. But it is rare for characters not present in either parent to appear in the offspring, and when extra-parental characters do appear they are usually unimportant ones or deficiencies. Consequently it was found possible to predict within fairly narrow limits what the offspring of any given cross would look like, with respect to such important characters as angle of bunch, number and size of fruits, and so on. Previously there had always been at least the theoretical chance that a good banana might result from a cross between "unlikely" parents, but accumulated experience showed the chance was so small as to be negligible. Henceforth parents could be chosen on the sum of their phenotypic characters, just as in most simpler plant breeding programmes, subject only to allowance being made for polyploidy, which often causes the characters of one plant to be more pronounced in the offspring than those of the other parent.

The establishment of this fact and of the cytogenetical generalizations already mentioned may be regarded as marking the end of the empirical phase of the researches, though there was no abrupt change of plan at any point but rather a gradual modification as information accumulated. With increasing knowledge of genetic behaviour came an increasing conviction that failure to reach the desired goal was largely, if not entirely, due to lack of the right breeding material. Emphasis had always been laid on the necessity for a large variety collection from which suitable material could be chosen; it came to rest more and more on the necessity for that collection to contain a wider range of fertile diploid forms, only obtainable by collection in the countries where they are indigenous.

The genetical and cytological data obtained indicate that the good qualities of tetraploid hybrids of the I.C. 1 type depend on the fact that they contain the complete gene-complex of their triploid female parents, whilst their defects derive from the added (haploid) gene-complex of their diploid male parents. The constitution of the parental triploids has been evolved through the accumulation of structural changes during hundreds of years of vegetative propagation, and can only reach its full expression as long as it works as an undisturbed unit. The defects of the tetraploids therefore cannot be removed in later generations, because in sexual reproduction of the tetraploid the unit is inevitably broken up, and the chances of recombining it are too remote to afford a basis for practical breeding. This theoretical appraisal of the situation by K. S. Dodds is supported by the actual results of tetraploid x tetraploid crosses, and forms the foundation of further attempts to produce a commercial tetraploid.

For the triploid or female side of the cross that is to give a useful export banana, everything points to the Gros Michel variety as the best available parent. Apart from its susceptibility to certain diseases, that variety has so many of the qualities required in the export trade that somebody has said it might have been specially created for the fruit industry. Many years' study of other established varieties by the fruit trade, as well as our own observations in Trinidad, have failed to find a satisfactory substitute for it, and to start with any other parent is to add unnecessary handicaps in a problem sufficiently difficult without them. At one time attention was given to the possibility of starting with an established variety immune to Wilt and trying to improve its commercial fruit characters, but there are several reasons why this is no longer considered feasible. The chief is that the most promising varieties for such a programme are completely sterile, which is one of the pieces of useful information accruing from negative results in the empirical investigations. Apart from that is the fundamental consideration that introduction of disease resistance by itself has proved the simplest part of the whole problem, whilst it is the commercial fruit characters that give all the trouble. Disease resistance is the rule rather than the exception amongst the fertile diploids. Thus in practice any male parent which would improve the fruit characters of an inferior variety would almost certainly give even better results on Gros Michel and solve the whole problem outright.

Virtually then, the problem narrows down to getting the right male-fertile diploid for crossing with Gros Michel. Such a plant may exist in a wild state in countries where *Musa* is indigenous, or it may have to be built up from a number of forms each good in some characters but deficient in others. If it could be found ready-made much time would be saved, as the synthesis from such material as is now available would at the best be a tedious undertaking. Strong representations to that effect having been made, plans were approved in 1939 for an expedition to the Far East to explore the variation of the nearest banana relatives in the wild state and to collect material of promising forms.

For reasons explained more fully in a later section of this paper, the region chosen for the first exploration was approximately that where Burma, Siam and Indo-China meet. It would be impossible to explore the whole of the vast area over which *Musa* is indigenous, and even the section of the genus that appears to be of the greatest interest covers an enormous area, but the centre of distribution seems from available evidence to be in the region specified.

Plans were suspended on the outbreak of war, and the political condition of the countries named does not at the time of writing afford much hope of their early resuscitation. The policy since 1940 has therefore been to concentrate on genetical researches, collecting data likely to hasten progress when new material becomes available, and at the same time to try how far a suitable diploid can be built up from the existing stocks.

Present Aims

The immediate or "short-range" aim of banana research is still to produce a new export variety resistant to Banana Wilt, otherwise known as Panama Disease, caused by the soil inhabiting fungus *Fusarium oxysporum cubense*. But without neglecting this object it is now possible to state aims in rather broader terms. Since the work started, additional urgency has been lent to it by the rapid spread in the Western Tropics of the Leaf-spot Disease caused by *Cercospora muscle* Zimm. Though the latter disease, unlike Wilt, has proved to be controllable by other means, a resistant variety would afford cheaper control than the present method of spraying. In the background there is always present the threat to the export trade of Bunchy Top, a virus disease that already causes serious losses in the East; and beyond that there is the possibility that at any time a new or hitherto unimportant disease may become prominent and create a need for further breeding. The problems of the banana as a local food crop have hitherto scarcely existed, partly because diseases are less serious when the plants are grown as scattered individuals among other species and partly because so many varieties are available that suitable ones can usually be found for any set of local conditions within banana-growing districts. This happy state of affairs may not always exist, and already the difficulty experienced in growing plantains in some districts points to wider uses for banana breeding.

There are good reasons, therefore, why banana research should be regarded as having a "long-range" aim quite consistent with its more immediate object. In other words, without for a moment losing sight of the urgent need for a "wilt-resistant Gros Michel" we may remind ourselves that the production of that plant is not likely to end banana-breeding. The long-range aim must be to obtain such a complete knowledge of genetic systems in *Musa* that new bananas can be bred as they may be required to meet any new problems that may arise in banana production.

Analysis of Problem

Disease resistance, though it is the primary desideratum, may fairly be said to present only a secondary problem. Resistance, both to Wilt and to Leaf-spot, occurs in many members of the banana complex, wild and cultivated, and is known to be transmissible. The primary problem is how to breed any commercial banana, in face of the fact that the essential character of a banana (its "edibility") is inseparably coupled with sterility.

The existing commercial bananas are undoubtedly the products of centuries of evolution. We do not know how long Man has been cultivating them, and selecting and preserving chance variations giving fruit more to his liking than that of wild plants, but it must be a long-time. It happens that all the best of the varieties so produced are triploid plants, and there is probably a reason for that fact which still has to be found, and which is likely to prove important.

So far, the only practicable method that has been found for utilizing these products of long evolution in breeding is to add to them a gene complex that will not detract from their good qualities and so to produce from them primary tetraploids. That is at present the main hope-of solution of the short-range problem, and it looks a very fair one if the right material can be found. The breeding of primary tetraploids, however, is no answer to the long-range question, which is, in essence, whether it is possible to imitate in a few controlled generations the process of centuries that has built up the primary triploids. Only when that can be done shall we be in a relatively safe position to meet the problems of the future in banana production.

The information required to that end covers a wide field of research, which may be appreciated by dividing it for discussion into five parts, although each line of work is dependent on the others.

We need:

1. Studies of a wide range of cultivated bananas, which must include attempts to discover their constitution by genetical methods.
2. Studies of wild species of *Musa*, primarily to determine which of them have been involved in the ancestry of the cultivated forms.
3. Studies of the incidence of polyploidy and the general breeding behaviour of diploids, triploids and tetraploids.
4. Studies of the incidence and inheritance of parthenocarpy, with attempts to discover the physiological mechanism through which it is expressed.
5. Analysis of the several causes of sterility in various forms of *Musa*.

Each of these lines has in fact already received attention, since the. observations incidental to the empirical attempts at banana breeding have provided a mass of relevant data and also material for further research. Each of them, however, still provides unsolved problems and must still be followed up. The position reached along each line will be briefly indicated.

Survey of Cultivated Forms

Nobody knows how many established varieties of bananas and plantains there are in cultivation. Most of the literature about the group emphasizes its diversity, but varietal studies tend to suggest that the diversity has been somewhat exaggerated. The question is not unimportant to the geneticist, for it affects fundamentally the picture that he must try to draw of the origins of the group.

In seeking the answer, we have first to define the term "variety". If we interpret it in its narrowest sense and apply it to every recognizable form, the total number may well be several hundreds. Some of these "varieties", however, will then differ from others only in single characters, such as colour of fruit or amount of wax on the epidermis. In such cases it is a justifiable assumption that two or more forms are descended from the same original seedling and that the variation has arisen through somatic mutation. There is plenty of evidence that somatic mutation (or "bud sporting") has played a part in the evolution of banana varieties: for example, in Jamaica Larter (Journ. Jamaica Agr. Soc. August 1934) has described no less than six bud mutants of the Gros Michel variety found in commercial plantations.

The important question to the geneticist is how many original zygotes are represented, or in other words from how many distinct individual seedlings the present population has been derived by vegetative propagation. It is not likely that an exact answer will ever be obtained, nor is a very close estimate necessary, but it should at least be possible to determine whether the number is to be measured in dozens or hundreds. At present, all we can say is that edible bananas have certainly been derived in more than one way from a number of different wild forms. The usefulness of knowing approximately the kinds of wild plants that were originally involved, and the steps by which their constitutions have been modified, should need no stress.

There are therefore ample reasons for the maintenance and continued study of a wide collection of edible bananas, in spite of the decision that for immediate breeding purposes the Gros Michel is the only one likely to prove useful. Every new variety that comes into the collection adds something to the sum of knowledge about the group; and a variety quite useless as breeding material may, by closing a gap in the research worker's information, contribute greatly to final success.

Studies to date on the existing collection have led to the hypothesis that all Indo-Malayau bananas and plantains can be classified into three main groups, derived from two natural species and hybrids between the two. This hypothesis provides a great simplification of the origins of the group, but the danger is that it may prove to be an over-simplification, based on an insufficient range of evidence. Observations in the future must therefore be directed to checking the hypothesis and if necessary amending it.

Survey of Wild Forms

The wild forms of *Musa* are of most immediate interest because it is among them that we hope to find the right male parent to solve the problem of the "wilt-resistant Gros Michel". They have still more importance in the long range problem of determining the origins and relationships of bananas in general.

The literature in 1922 contained well over a hundred specific names published under *Musa*, with good or fair descriptions of about forty species, classified into three subgenera and distributed over practically the whole of the Old World tropics. The relationship of the cultivated forms to the wild was little understood and theories about it conflicted. The first problem was therefore to find out how many species were probably concerned in the ancestry of the bananas or sufficiently closely related to be potential breeding material, in order that. effort could be concentrated on the collection and study of those instead of being dissipated over an unnecessarily wide field.

This kind of problem has to be tackled by the collation of information from several sources. Much can be obtained from literature, though it is widely scattered and often in publications. difficult to obtain. Some can be got from dried fragments in herbaria. More is forthcoming from correspondence and most from the material that comes into the collection by the good offices of co-operative correspondents in many countries.

By such methods it has been possible to arrange the available knowledge of *Musa* and step by step to eliminate large sections of the genus as not sufficiently closely related to the bananas to be potential breeding material. Recent publications have suggested the removal of a number of ‘species to the genus *Ensete* Horan., and the classification of those remaining into four sections. Of the four sections only one (*Eumusa*) is judged to be involved in the banana complex, and it consists of no more than half a dozen described species. Of these, as noted above, only two seem to be directly involved in the ancestry of the bananas, but these two are widely distributed and variable, one of them extremely variable.

Our knowledge of these particularly important species is still fragmentary, but enough to show that they are by no means simple. Even in wild forms there are certain irregularities in the reproductive mechanism which must certainly be understood before we can hope to analyse the much more complex systems of the cultivated plants. Again it is only by survey of a sufficiently wide range of material that gaps in knowledge can be filled in.

Polyploidy

Gros Michel and the majority of edible bananas are triploid (2n = 33) . All known wild species are diploid (2n = 22). The economic significance of the triploid condition is still obscure. The occurrence of perfectly edible (parthenocarpic and seedless) diploids among the established varieties shows that polyploidy is not an essential character of an edible banana. On the other hand, all the edible diploids known to us are slenderer plants than the average triploid and produce smaller fruits. There may well be some connection between polyploidy and fruit size, but it would not appear to be a simple or direct one. Tetraploids and higher polyploids are only known among artificially produced hybrids and nothing higher than a pentaploid has ever been raised to flowering : even pentaploids are not very vigorous. Interest therefore centres mainly on the triploids and tetraploids.

As triploidy introduces further complications into a genetic system which is already complicated in the parthenocarpic diploids, little has been done towards the direct cytogenetical analysis of the triploid clones. The principle has been to work from the simpler to the more complex, and this means that most work to date has been done on the diploids.

Polyploidy has, however, been studied further in species hybrids where it is not associated with parthenocarpy; and one of the most interesting results is the finding that in *Musa* polyploidy frequently occurs as a result .of wide species crossing. Several species hybrids, when selfed or backcrossed with their parents give either triploid or pentaploid progeny, or a mixture of both.

How far this information may ultimately help to explain the origin of polyploidy in the edible bananas cannot be stated. But it is evidently a useful addition to our knowledge of genetical behaviour in the genus.

Parthenocarpy

Parthenocarpy is essential in an “edible” banana, and therefore of the greatest importance. One difficulty in studying it is that it seems to be inseparable from some degree offemale sterility. A parthenocarpic form may however, be fully fertile on the male side, and studies of inheritance are therefore possible. Detailed results of such studies by Dodds and Siminonds are at present * in the Press. They show *inter alia* that parthenocarpy can be transmitted through the pollen of parthenocarpic forms, and that it depends on a single dominant gene, though its expression is affected by modifiers.

* i.e. in July 1948.

Parthenocarpy has so far been reported in *Musa* in only three species, two of which are the putative parents of the Indo-Malayan bananas. Even those species have numerous non-parthenocarpic forms, and parthenocarpy has not so far been induced in any form where it does not occur naturally. Knowledge of its behaviour has, however, already been turned to account in the synthesis of one banana variety.

A cross between a parthenocarpic, male-fertile, diploid form of M. acuminata Colla and a non-parthenocarpic diploid form of *M. Balbisiana* Colla gave a plant closely similar to an established variety carried in the collection as Type-20. The result not only helps to prove the hybrid nature of Type 20, but may be regarded as probably only the first step towards further success in the synthesis of genotypes imitating established varieties with great consequent gains in our knowledge of the constitutions of those varieties.

Sterility

Sterility in the bananas is of practical importance whether regarded as an essential feature of any commercial genotype or as the greatest obstacle to breeding operations. From either point of view the analysis of its causes is necessary.

Research to date indicates that some female sterility is probably inseparable from parthenocarpy, representing another expression of the same factors. Some sterility of both sexes in triploids must be ascribable directly to the triploid state. In addition to these causes, structural sterility, which can be demonstrated in certain non-parthenocarpic diploids, must complicate the situation in the parthenocarpic polyploidy. In certain clones, though not in all, there is good evidence of species hybridity as a possible fourth factor inducing sterility.

The investigation of sterility thus provides a connecting link between botanical survey, studies of polyploidy, and studies of parthenocarpy. Direct analysis of the complicated forms must be written off for some time to come as quite impossible. But by proceeding from the simpler forms to others a little more complex, and working simultaneously along the several lines that have been discussed, progress is being made.

Summary

An account has been given of botanical researches on bananas at the Imperial College of Tropical Agriculture since 1922.

The immediate object of the researches is the production of a commercial banana .combining resistance to certain diseases with suitability for the export trade.

The long-range object pursued simultaneously is to obtain such knowledge of the origins, relationships, and genetic systems of the group as will facilitate banana breeding in general in case new needs for it arise.

Many years were spent in attempts to produce the desired type by methods that are largely empirical ; but the information so obtained finally permitted analysis of the problem and formulation of a more scientific programme.

An attempt has been made to show how botanical studies of wild and cultivated forms, and studies of polyploidy, parthenocarpy and sterility have to be integrated to the desired end.

Publications

The following is a chronological list of papers on the botany and breeding of bananas (excluding pathology and fruit storage research) that have been published from the Imperial College of Tropical Agriculture:-

1925 Dash, J. S. - Bananas from seed. Proc. 9th *W.I. Agric. Conf., Jamaica,* 1924, pp. 53-56.

1928 Harland, S. C. - Bananas and Citrus. *Trop. Agriculture (Trin.)* 5 : 23-24, 54-56, 90-91.

1931 Cheesman, E. E. - Banana breeding at the Imperial College of Tropical Agriculture. *Empire Marketing Board Publ.* 47, H.M.S.O., London.

Cheesman, E. E., A note on *Musa ornata*. Kew Bull. 1931 ; 297-99.

1932 Cheesman, E. E. - Genetic and cytological studies of *Musa* L. I. Certain hybrids of the Gros Michel banana. *J. Genet.* 26 : 291-312.

Cheesman, E. E. - Genetic and cytological studies of *Musa* L. II. Hybrids of the Mysore banana. *J. Genet*. 26 : 313-16.

Cheesman, E. E. - Gros Michel and Pisang Embun. *Trop. Agriculture (Trin.)* 9: 87 and 166.

1933 Cheesman, E. E. - Mutant types of the Dwarf banana. *Trop. Agriculture (Trin.)* 10: 4-5. Cheesman, E. E., Wardlaw, C. W. and Spencer, G. E. L. - The Cavendish group of banana varieties, with special reference to Lacatan. *Trop. Agriculture (Trin.)* 10: 218-221.

1934 Cheesman, E. E. - Principles of banana breeding. Trop. Agriculture (Trin.) 11 : 132-37 ; 176-81 ; 203-208. (Reprinted with change of pagination as *Memoirs of the Imperial College of Tropical Agriculture, Botanical Secries* No. 3, 1934).

1935 Cheesman, E. E. and Larter, L. N. H. - Genetical and cytological studies of *Musa* L. III. Chromosome numbers in the *Musaceae*. *J. Genet.* 30: 31-52.

1937 Cheesman, E. E. and Wardlaw, C. W. – Specific and varietal susceptibility of bananas to Cercospora leaf spot. *Trop. Agriculture (Trin.)* 14 : 335-36.

1942 Cheesman, E. E. and Dodds, K. S. – Genetical and cytological studies of *Musa* L. IV. Certain triploid clones. *J. Genet.* 43 : 337-57.

1943 Dodds, K. S. - Genetical and cytological studies of *Musa* L. V. Certain edible diploids. *J. Genet.* 45 : 113-138.

Dodds, K. S. - The genetic system of banana varieties in relation to banana breeding. *Empire. Expt. Agric.* 11 : 89-98.

1945 Dodds, K. S. - Genetical and cytological studies of *Musa* L. VI. The development of the female cells of certain edible diploids. *J. Genet*. 46 : 161-179.

1946 Dodds, K. S. and Pittendrigh, C. S. - Genetical and cytological studies of *Musa* L. VII. Certain aspects of polyploidy. *J. Genet.* 47: 162-177.

Dodds, K. S. and Simmonds, N. W. - Genetical and cytological studies of *Musa* L. VIII. The formation of polyploid spores. *J. Genet.* 47 : 223-241.

Dodds, K. S. - *Musa* Fehi. *Nature* 157 : 729-730.

1947 Cheesman, E. E. - The genus Ensete Horan. *Kew Bull.* 1947 : 97-106.

Cheesman, E. E. - A new classification of the genus *Musa* L. *Kew Bull.* 1947: 106-117.

1948 Cheesman, E. E. - Notes on species of *Musa* L. *Kew Bull.* 1948.

Dodds. K. S. and Simmonds. N. W.-Genetical and cytological studies of *Musa* L. IX. The origin of an edible diploid and the significance of interspecific hybridisation in the banana complex. *J. Genet.* 48 : 285-296.

Dodds, K. S. and Simmonds, N. W. - Sterility and parthenocarpy in diploid hybrids of *Musa*. *Heredity* 2 : 101-117.

Received for publication July, 1948.

Extracted from Volume 30, Number 1, 1953

COMMUNICATIONS ON ORIGINAL INVESTIGATIONS

RED RING DISEASE OF COCONUTS IN TRINIDAD AND TOBAGO

BY *E. B. MARTYN*

(Plant Pathologist, Department of Agriculture, Trinidad and Tobago)

SUMMARY

A short account is given of the origin of red ring disease of coconuts in Trinidad, its distribution elsewhere, and early investigations of the disease. Reference is made to serious losses caused in recent years. The symptoms of the disease are described and shown to be associated with the production of a strongly reducing substance in the periphery of the cortex of young palms invaded by the nematode *Aphelenchoides cocophilus*.

Experiments on the inoculation of stems and roots are described. These showed penetration via the leaf axils to be the normal means of entry of the parasite, root infections, though successfully carried out artificially, being of no account under natural conditions. The coconut weevil, *Rhynehophorus palmarum*, and by inference *Rhina barbirostris*, also was shown to be able to transmit the disease by burrowing in diseased debris in the cortex of affected palms, emerging with legs and body covered with this debris, and transferring it to wounds or to leaf axils in adjacent palms.

Reference is made to reports of natural and artificial alternative hosts of the parasite, and it is concluded that under natural conditions the disease is confined to the coconut palm, at least in the Lesser Antilles.

Control of the disease is shown to be possible by the removal of all infected palms and complete destruction of diseased tissues by fire.

INTRODUCTION

Red ring disease of coconuts, due to the colonisation of the periphery of the cortex of young palms by the nematode *Aphelenchoides coeophilus* (Cobb), is an endemic disease of South and Central America. It is known in Brazil, Venezuela, Colombia, Panama, and British Honduras, but its once reported presence in British Guiana is incorrect. The disease has also, in course of time, found its way from the mainland to Trinidad, Tobago, Grenada, and St. Vincent in the Lesser Antilles.

Red ring was known in Trinidad and Tobago fifty years ago as ‘root disease’, under which name it was studied by several mycologists, until in 1918 Nowell, investigating the disease in Grenada, realised the significance of the eelworms found so plentifully in the affected tissues, and showed them to be the cause of it. The nematode concerned was examined and named by Cobb (1919), and further experimental work by Nowell and Ashby (1919-1924) threw more light on the aetiology of the disease. Though failing to discover its means of spread, they stressed the importance of complete and effective destruction of affected palms by fire, and also suggested trenching to contain the nematodes; there the matter remained for some thirty years.

Apparently, when the Trinidad coconut industry was expanding in the second and third decades of the present century, the disease did not cause excessive damage in the new plantations, doubtless because it was absent in most of the newly planted areas to begin with, and did not have time to build up a large source of potential infection before the plants passed the most susceptible age—four to seven years old. The subsequent supplying of these plantations was generally carried out haphazardly, either by casual planting in gaps that arose, or by leaving these to be filled by ‘drop nuts’ conveniently germinating near the right place. The result was that the older plantations always contained a number of young palms of varying age, scattered, and not all at the age of greatest susceptibility. Losses from the disease were sometimes quite extensive, but on the whole the deaths did not seriously affect output and were accepted as inevitable.

0041-3216/2021/030218-225

In some cases planters took phytosanitary measures to check the rate of spread.

In recent years, however, coconut planters on the East coast of Trinidad, after felling the original palms, have started replanting whole fields with seedlings, raised in nurseries from selected nuts. In such plantings, all the young palms in a field reach the age of maximum susceptibility at the same time, and the disease has been causing such serious losses (in some cases over 60 per cent. by the fourth or fifth year) that rehabilitation of the plantations in this manner seemed impossible to achieve. Consequently the planters concerned asked for further investigation of the disease, and this was carried out at Nariva-Cocal, where heavy loss had been sustained.

DESCRIPTION OF THE DISEASE

The appearance of the disease was well described by Nowell (1923), his account being quoted in most subsequent references. The initial yellowing and subsequent drying out and browning, of the leaves can, however, occur in palms affected by other adverse factors. The leaf colour changes generally start with the oldest leaves, the occasions when younger leaves are first affected being due no doubt to primary infection higher up the stem. The age and size of palms attacked varies somewhat in different accounts of the disease; but, in general, coconuts are most susceptible from the time they first form a clearly defined stem with a cortex of soft tissue till the time when this cortical tissue hardens. This period, of course, varies with the conditions under which the palms grow, but in Trinidad is generally from the fourth to the seventh year. In Brazil the disease is recorded on palms up to ten years of age (Joffily, 1948).

Artificial infection of the stem resulted, as a rule, in the appearance of external symptoms about six weeks later, though occasionally, they appeared before and sometimes were delayed for eight weeks or so. The rate of growth of the palm and prevailing weather conditions are relevant factors in the rapidity with which the symptoms develop.

The red ring forms about two inches from the periphery of the stem, starting as a faint but quite distinguishable line around it, and soon developing into a band some one to one and a half inches in width, often red-brown to brown rather than red in colour. The nematodes are massed in this area, to which they are almost entirely confined, and where they apparently encounter optimum conditions. Aeration and water supply are probably the determining factors that account for their absence nearer the centre of the stem, and the harder tissues confine them on the outside, so defining the limits of the ring. After the cortical tissues harden they are apparently not favourable for the existence of the nematodes, which no doubt accounts for the general absence of the disease in older palms. In addition to the red ring area of the trunk, nematodes may be found generally distributed in the ground tissues of infected petioles.

The discolouration of the tissues is associated with the presence of a high nematode population, and in the orange-brown zone strongly reducing conditions are found. The destruction of this zone of tissue is apparently the direct cause of the external leaf symptoms and subsequent death of the palms, which may be due to the toxic substances formed, but the actual mechanism of the destructive process is obscure.* Leaf symptoms probably depend to some extent on whether direct infection of the petiole or secondary infection from the stem occurs. Growth of the palm sometimes continues for a week or so after external leaf symptomis are evident, or may cease rather sooner.

---

*The writer is indebted to Mr. K. W. do Witt. of the Imperial College of Tropical Agriculture for kindly investigating this matter. He reported as follows :—

" In the course of a chemical examination of the tissues of Coconut palms affected by red ring disease it was observed that in an advanced state of the disease the red ring area of the cortex exhibited highly reducing properties towards ammoniacal silver nitrate solution. A drop of the reagent applied to the red ring was blackened within 10-15 seconds, whereas in all other parts of the cross section of the trunk several minutes elapsed before darkening was noted. In healthy palms, and in those in very early stages of the disease, no such effect was obtained.

The reducing material present in the reddened tissue was water soluble, and was estimated by titration against 2-6-dichlorphenol indophonol (Harris & 011iver, Biochem J. 36, 155, 1942). Results, expressed as ascorbic acid, are given in the following table:—

Distance from periphery of trunk (c.m.)		
0-4	4-6.5 (red ring area)	7-30
Reducing material (mg. ascorbic acid/ 100 gm tissue)		
3.2	63.0	1.2

Thus the reducing power of the tissue in the red ring is 20-60 times greater than in other parts of the trunk."

The red ring is the surest symptom of the presence of the disease. A brace and inch bit, the latter penetrating to a depth of three inches, withdraws tissue in which the typical discolouration can be noted and the disease recognised, two or three weeks before external symptoms appear, and without the necessity of felling the palm. Such borings are readily repaired with a wooden plug and a covering of plasticine, to prevent the attraction of weevils.

STEM INOCULATION EXPERIMENTS

(a) Very young plants

Attempts were made to infect young palms (about two years old) in which the leaves were just becoming pinnate, growing in tubs. As in subsequent experiments, pieces of red ring tissue were placed in water in a funnel, and allowed to stand for a while, after which the water, containing large numbers of nematodes, was drawn off from the stem of the funnel for use as inoculum, either as it was, or after dilution. Water containing nematodes was poured over the plants, the petioles of which had in some cases been nicked with a scalpel. In other experiments, with similar palms, pieces of red ring tissue were inserted in wounds in the petioles, or placed in the leaf axils. In no instance was infection obtained. (Ashby (1921 b) claimed to have once artificially infected an eleven-month-old palm in the field, though failing with similar plants in pots.)

(b) Older palms

Inoculation of older palms was carried out in the field, in areas where the disease had not yet appeared, so that natural infection was unlikely to occur. Palms of about four years old were successfully inoculated by repeating Nowell's methods, i.e. placing pieces of diseased tissue in wounds in stems and petioles, or in unwounded leaf axils. In these cases, however, there was the possibility that some fungal or bacterial organism in the diseased tissue, and not the nematodes, might have caused the infection. Other palms were therefore inoculated simply by introducing the nematodes in water to the leaf bases with a pipette. Nine palms were inoculated in this manner, and infection was obtained in every case, in some instances during the dry season. It is not only apparent, therefore, that the nematode alone causes the disease, but that it can readily gain entry via the leaf bases, as Nowell believed, and this, as will be shown, is no doubt the normal way of infection.

An attempt to inoculate a palm of some 20 years of age by boring holes in the trunk and inserting pieces of red ring tissue—a certain means of infecting younger palms—failed to cause infection.

Attempts were made to establish the eelworms in portions of trunk about two feet long, cut from the stem of a young, healthy palm and trimmed of leaf bases. These were brought to the laboratory, stood upright in trays of water, and the cut surface at the top kept covered with moist filter paper. These pieces were kept thus for 10 days, the cortical tissues remaining apparently fresh throughout this period. A number of borings were made with brace and bit, into which were introduced nematodes in water, or pieces of red ring tissue, and the holes were then plugged. In no case did the nematodes establish themselves in the cortical tissues, and it seems evident, therefore, that for their well-being and multiplication the natural movement of solutes in the tissues of the living plant is necessary. The removal of staling products is no doubt essential.

ROOT INOCULATION EXPERIMENTS

Examination of roots of diseased palms showed nematodes to be present in the cortex of older hard, brown anchoring roots that emerge directly from the base of the trunk; but they were not found in the younger, lighter coloured feeding roots, nor in washings from soil taken from around diseased palms.

As in other cases when the presence of eelworms was looked for in soil or tissues, the material was allowed to stand in water in a funnel, if need be overnight, a sample of the water being then run off and examined for nematodes.

(a) Very young palms

Attempts were made to inoculate the roots of three two-year-old palms just forming pinnate leaves, and growing in tubs, by burying pieces of diseased tissue among the roots. One palm was dug up after a week, another after two weeks and the third, still apparently healthy, after a lapse of five months. The roots were washed and examined, but in no case were eelworms found in them.

In another experiment, six germinated dwarf coconut seedlings with shoots three to four feet high and roots about one foot in length were stood in glass jars in the laboratory, the roots being submerged. The roots of three of these were damaged by cutting off portions, particularly of the larger ones, with scissors. Water containing nematodes was then added, and in addition pieces of infected tissue were placed in the jars, so that they floated among the roots. After a week the roots were examined, but no nematodes were found in the tissues.

(b) Older palm

Inoculations of four-year-old palms were carried out in the field by burying large pieces of red ring tissue among the roots near their bases. Three palms so treated on May 27th showed no red ring tissue when bored on July 15th, but by August 19th they showed early leaf symptoms and the presence of red ring was confirmed by boring. This experiment was then repeated, three more palms having diseased tissue buried among their roots on August 19th. Again, on September 2nd, three more palms were inoculated by pouring water containing nematodes into a shallow trench dug around the base of the trunks. On October 7th, though no external symptoms had appeared, roots from one palm of each of these two latter sets of inoculations were dug up. Some of them were obviously discoloured and eelworms were plentiful in them. On October 21st all six palms were bored, and although no external symptoms were yet visible, one of each set of three was found to contain red ring tissue.

On the same day samples of soil, containing portions of the finer roots, were dug up from near the base of the two palms showing red ring tissue, and the soil (a very sandy loam) was sifted, separating the roots and lumps of soil from the bulk of the finer soil. In the case of the palm around which water with nematodes had been poured, a few individuals of *A. cocophilus* were found in the fine soil separated from roots, and also in the siftings containing pieces of fine root, but other species of nematodes were more prevalent. In samples of soil in which pieces of diseased tissue had been buried, *A. cocophilus* could not be found, though other species of nematodes were plentiful.

All but one of these root-inoculated palms subsequently developed external symptoms, at varying times during November, showing that infection by this route is slower than through the leaf arils or stem. One of the last series (eelworms in water added to the soil) did not become infected and was still healthy on December 16th.

(c) Conclusions from root inoculation experiments

It would appear from these experiments that *A. cocophilus* does not build up large concentrations in the soil, as some of the earlier investigators believed; hence their recommendation of isolation trenches. It would seem, moreover, that although root infection can be brought about artificially and might occasionally take place naturally, it is not a normal method of initiation of the disease; for in the ordinary course of events the nematodes would not find their way into the soil or persist there in sufficient numbers to give a reasonable chance of infection. If a persistent source of inoculum is present (e.g. buried red ring tissue, which has been found to remain quite fresh for two weeks after burial), or if a high concentration of *A. cocophilus* is brought about by adding it in water to the soil, the nematode presumably gains entry through damaged or senescent roots. It then multiplies in the tissues, and eventually works its way up into the trunk, producing the usual symptoms. Failure to secure infection of roots of seedling palms in water may have been due to a too short exposure, or to the preference of the nematodes for the water rather than the root tissues. Failure to infect palms in tubs may have been due, in part, to lack of enough senescent larger roots to give entry, and to absence of suitable tissue in these young palms for the nematodes to multiply.

NATURAL TRANSMISSION OF THE DISEASE

It has been suggested that the nematodes travel from one palm to another in continuous films of water during rain, flooding or the presence of heavy dew. At Cocal this was demonstrably not the case. The disease spread with equal rapidity in the dry season when, moreover, owing to the proximity to the sea, there is very little dew, and was if anything more extensive on higher and better drained land near the sea than on swampy land near an adjoining river.

On the other hand. it has always been the opinion of observant planters in Trinidad that the Coconut weevils *Rhynchophorus palmarum* and *Rhina barbirostris* play a part in spreading the disease. They are readily attracted to young palms by the fermentation of small quantities of sap exuded from the slightest injury to the soft tissues. Older, hardened palms do not attract them unless more extensively damaged. Ashby (1924) made reference to the reported transmission of the eelworm on the snouts of coconut weevils in Central America, and it is evident that where these weevils abound the disease is more prevalent than where they are scarce. The East Coast Coconut areas (Nariva, Mayaro, Guayaguayare), where red ring has been so much in evidence, suffered from lack of attention during the war years and the weevils have become very abundant there. On the other hand in the Cedros area, where the disease was originally observed, it is of no account, and apparently caused no serious loss in the areas replanted after the 1933 hurricane; but coconuts there are mostly estate grown and active steps have always been taken to check weevils. Similarly, in Tobago the disease is of little importance on the well managed plantations at the South-East end of the island, but does considerable damage in neglected coconut plantings elsewhere. Finally, it has been remarked (Briton-Jones, 1940) that coconuts established through cane, as opposed to secondary bush, seldom contract the disease. In this environment the necessarily clean surrounding cultivation leaves no breeding place for coconut weevils.

It was therefore considered desirable to investigate the possible action of coconut weevils as vectors of the disease, the moreso as it had been recently stated (Tidman, 1951) that in Brazil infection was spread by R. palmarum feeding on diseased tissue and carrying the nematodes in its intestines and faeces. It subsequently transpired that the report on this means of transmission was based on inaccurate information, but in the meantime experiments were carried out in Trinidad to test the validity of this alleged method of transmission. Firstly, weevils obtained from the leaf bases of diseased palms and then placed in jars with red ring material were subsequently dissected, but no nematodes could be found in them or in their faecal pellets. Large pieces of infected tissue, which would inevitably attract weevils, were left on the ground under young palms, but no infection occurred. Plastic bags were devised to hold wedge—shaped portions of infected tissue and allow access of weevils whilst preventing the direct escape of nematodes in moisture. Three of these bags were placed in leaf axils of each of four palms and left there for two weeks, but though weevils visited the contents, and would then go into the leaf axils, no infection resulted. It is therefore evident that direct transmission by the mouth parts or through the intestinal tract does not take place.

It was observed, however, at Nariva-Cocal that R. palmarum was always present in large numbers and was often found in the leaf axils of the palms, especially those of the bottom leaves. The larvae were invariably found tunnelling in the stems of any diseased palms felled and left lying, and sometimes in the stem bases of palms still disease-free, the eggs apparently having been laid by adults attracted by some injury at the base of the stein and entering thereby. Though *Rhina barbirostris* was seldom seen on this plantation, it was quite abundant in the Mayaro area, where planters reported it to be readily attracted even by the slight ooze of sap following the partial or complete removal of a leaf from its stem attachment, either in the course of agricultural operations or otherwise.

At Cocal, two diseased palms were cut down and left lying to attract *B. palmarum*. These were visited on the evening of the day after felling, and it was noted that weevils had by then burrowed into the diseased tissues. When removed they were covered with small pieces of debris, all heavily colonised by *A. cocophilus*. In one experiment, two such weevils were placed in a hole bored in the trunk of a healthy palm, confined there by gauze tacked over the hole, and removed after about 12 hours. In two other experiments, weevils taken from diseased tissue in which they were burrowing were kept overnight in a tin containing pieces of red ring tissue, and the following morning placed in holes bored in healthy palms and left for a day. Within two months all three palms showed red ring symptoms. One was then cut down and the trunk found to contain a number of larval tunnels of *R. palmarum*, caused by the progeny of weevils attracted to the wound made for insertion of the insects at the start of the experiment. Several adults were found burrowing in the debris of these tunnels, which were in the red ring area. Two covered as before with infected debris, were removed and placed in holes bored in the trunks of two healthy palms. The weevils were again confined to the holes by gauze, and in this case left there, the cover being maintained over the holes. These palms were examined four weeks later by borings with brace and bit, and both found to have red ring.

It is evident, therefore, that the disease is spread by the coconut weevil acting as a carrier of infected debris, rather than of individual nematodes. It is to be expected that those carried on the surface of the insect without protecting plant tissue will die from desiccation, and there is no evidence for transmission of nemas on mouth parts or their survival in the faeces. Thus weevils merely feeding on the surface of infected tissue will not act as vectors, but after burrowing in diseased tissue and becoming covered with debris, they do. The debris-covered weevils may enter holes made by other weevils, transmitting the disease in the manner of the experiment, but doubtless more generally they fly to adjacent palms and crawl down into the leaf arils (usually those at the base of the palms, but sometimes higher ones) depositing there pieces of diseased tissue, from which infection can take place. It is noticeable that most new infections arise in palms immediately adjoining those already diseased; weevils taking longer flights probably lose much of the debris when in the air, but the periodic occurrence of new outbreaks in hitherto unaffected areas can be accounted for by the retention of some of it.

Urich and Guppy (1911) made some preliminary observations on R. palmarum in Trinidad, and found that the time from egg laying to moulting of the larvae in two instances was 74 and 128 days respectively, and from formation of the cocoon to emergence of the perfect insect 59 and 33 days respectively, indicating a life cycle of about four to five months. The larvae tunnel in the soft tissues of the cortex, which soon rot in a dead palm, but the cocoons are found near the periphery of the stein, i.e. in the red ring area, and the adult emerges through the outside of the stem. Portions of trunk from a diseased palm, cut down on June 19th and left in the field, were brought to the laboratory on July 10th, by which time they contained many larvae. They were placed in an insect cage in a shaded spot, to see if adults could be obtained. The cage was exposed to rain, and being also shaded, the stem pieces rotted too quickly for completion of the life cycle. Despite this, when a piece of the softened periphery of the stem, in which the cortex had entirely rotted, was cut open on October 9th, traces of red ring were still to be seen, and a few live individuals of *A. cocophilim* were found, although other species of nematode were present in much larger numbers. It is, therefore, evident that in the field, especially in the absence of shade, the life cycle may be completed and adult weevils emerge from the trunks of diseased palms with *A. cocophilus* still present. Therefore the nematode may also be carried in debris on the bodies of emerging adults.

Whether other insects can carry infected debris similarly is a matter for speculation. Ants have been suggested as vectors of the disease in Venezuela (Bain and Fedon, 1951), though the method of transmission was not specified. They do not appear to play such a part in Trinidad.

ALTERNATIVE HOSTS

The literature contains reference (Goodey, 1940) to the disease having been found on a date palm and on oil palm in the Trinidad Botanic Gardens, the reference quoted being the Annual Report of the Trinidad Department of Agriculture for 1925. Search in this and contemporary reports has, however, failed to discover the reference.

Nowell (1924) reported having successfully inoculated the cabbage palm (*Oreodoxa oleracea*) and obtained rapid death, and another successful inoculation of this species has been reported to the writer ; but, on the other hand, this palm, a native of Trinidad, grows plentifully in the Nariva swamp immediately adjoining the plantation where these investigations were carried out, and remains unaffected, presumably because *Rhynchophorus* does not attack it. Nowell also reported successful though slow infection of the gru-gru palm (*Acracomia aculeata*), another common native palm iu Trinidad, but in this case too natural infection is never observed. He also referred (1923) to the natural occurrence of one case of the disease on an unidentified species of Cocos and it seems possible that such might arise from a chance infection due to *Rhynchophorus.*

Red ring would, therefore, appear for all practical purposes to be confined to the Coconut. The nematode appears to have no means of prolonging its existence outside this palm, and no resting stage has been discovered. The origin of the disease on the mainland and the possibility of a wild-palm host there must remain a matter for speculation. Its appearance in the southern islands of the Lesser Antilles can, with reasonable probability, be attributed to its having been seaborne from the mainland by floating stems of diseased palms in which the nematode had remained viable.

CONTROL OF THE DISEASE

This can be effected by removal of sources of infection and reduction in the number of coconut weevils. Proper phytosanitation achieves both ends. The first essential (and it may be noted that this operation was recommended, amongst others, by Nowell in 1920) is the effective destruction of red ring infected tissue by fire, unless it can be conveniently buried where it cannot be a cause of abnormal root infection. However, the trunk of a young coconut palm contains a high percentage of water, and fire applied to the outside scarcely affects the inner tissues. Diseased trunks must be cut down flush with the ground, or, better still, cut off from the roots and removed from the soil entirely, which is not too difficult with young palms on sandy soil. The trunks must be cleaned of the attached leaf bases and cut up into lengths of about two feet, which must then be split lengthwise, so that the axe cuts expose the red ring area. These pieces and the rest of the debris should then be heaped up, on top of the stump if one is left, and burnt. By using coconut husks, with paraffin to start fire, this can be done effectively, though it is generally necessary to burn at least twice to ensure that no infective red ring tissue is left.

This control measure, besides removing the only source of infection, removes the main breeding ground of the weevils. (As has been pointed out above, roots left in the soil are of no consequence.) If it has to be done in an area where the disease has been allowed to become widespread, initial expense is high ; but once the work is completed, it is only necessary to keep a look out for new cases, resulting from infection brought from sources outside the plantation, and deal with them immediately. Just after the initial clearing, of course, a number of infected palms that were symptomless when the others were out may manifest the disease, and the operation of felling and cutting in a badly diseased field with weevils present can, by disturbing them, cause new infections. The danger, once thought to occur, of spreading the disease by chips flying from the axe when felling affected palms, is non-existent, since soil infection does not result. The chips cannot be carried by weevils, and they soon dry out, resulting in the death of the nematodes inside.

The effectiveness of control by proper destruction of diseased palms was indicated in two fields of young palms of susceptible age at Cocal, in which only a few instances of the disease had occurred when the appropriate action was taken. These infected palms were cut and burnt in August and September. One subsequent case appeared in each area late in September, after which no more diseased palms were seen in either field up to the end of December. Complete destruction of diseased trunks has also been reported to give successful control in Brazil (Ferreira Lima and Marques da Cruz, 1945).

The possibility of using a systemic pesticide was considered, and a few experiments were carried out with proprietary substances, which failed, however, to kill the nematodes in the stems of affected palms. The most promising line of attack, if a suitable chemical could be found, would be the prophylactic treatment of palms in the immediate neighbourhood of infected ones. Once a palm shows external symptoms the nematode population in the red ring area is such that destruction of the nemas with concomitant survival of the palm (which will by then have almost ceased growing) seems most unlikely. Moreover, if the nematodes were killed and the palm died, although the immediate source of infection would be removed, the dead palm would become a breeding place for coconut weevils when the pesticide in the tissues had broken down.

ACKNOWLEDGMENTS

My thanks are due to Mr. W. T. Dale of the Imperial College of Tropical Agriculture for reading this paper in draft and making many helpful suggestions, and to Mr. R. G. Fennah of the Imperial College of Tropical Agriculture, who had begun investigating this disease when with the Department of Agriculture, and with whom many aspects of it were discussed.

REFERENCES

ASHBY, S. F. (1921-a). Some recent observations on Red Ring Disease. *Agricultural News*, 20, 334.

(1921-b). *Ibid*, 350-351.

(1922). Experiments on Red Ring disease of Coconut in Grenada. Agricultural News, 21, 94-95.

ASHBY, S. F. AND NowELL, W. (1924.) Red Ring disease of Coconuts. *Proceedings of the Ninth W.I. Agricultural Conference, Jamaica*, 1924, 184-172.

BAIN, F. M. AND FEDON, S. A.(1951). Investigaciones sobre Anillio Rojo del Cocotero. Agronomia Tropical, July - September, 1951, Maracay, *Venezuela*.(Translation of summary seen only).

BRITON-JONES, H. R. (1940.) The Diseases of the Coconut Palm. *Bailliere, Tindall and Cox, London*.

COBB, N. A. (1919). A newly discovered nematode, *Aphelenchus cocophilua*, n.sp. connected with a serious disease of the Coconut Palm. *W. I. Bulletin*, 17(4), 203-210.

FERREIRA LIMA, A. D. AND MARQUES DA CRUZ, H. (1945). 0 anal vermelho do coqueiro. Bol. *Fitossanitario, Rio de Janeiro*, 2, 87-114.

GOODEY, T. (1940). The Nematode parasites of plants catalogued under their hosts. *Imperial Bureau of Agricultural Parasitology (Helminthology)*

JOYPILLY, J. M. (1948). A doenca do anal vermelho do coqueiro e sue, ocorrincia noBrasil. *Serv. Nac. Pen. Agron. Rio de Janeiro. Bol.*, 3, 64 pp.

NOWELL, W. (1918). Root disease of Coconut Palms in Grenada. *Agricultural News*, 17, 398-399.

(1919-a). The Root Disease or Red Ring Disease of Coconut Palms. *Agricultural News*, 18, 46.

(1919-b). Red Ring Disease of Coconuts. *Ibid*, 398.

(1923). Diseases of Crop Plants in the Lesser Antilles. *The West India Committee, London*.

TnameN, D. A. (1951). Agricultural and Horticultural Problems of Brazil. *World Crops*,3 (9), 341-344.

Unica, F. W. AND GUPPY, P. L. (1911). Preliminary notes on some insects affecting the Coconut Palm. *Circular No. 5, Board of Agriculture, Trinidad and Tobago,* 31 pp.

(Received for publication, January, 1953)

Extracted from Volume 35, Number 3, 1958

Mango Propagation by a " T " Graft Method

I. HOSEIN
Department of Agriculture, Trinidad and Tobago

The accepted method of propagating mangoes in Trinidad is by 'inarching' or as it is also called `approach grafting'. This is one of the oldest methods used for the propagation of mangoes and records of its use in India date back to ancient times.

The inarching method consists of the growing of rootstocks in containers for about 12 to 18 months until they have attained a size of at least 3/8 in. to 1/2 in. in diameter when they are grafted on to scions while the latter are still attached to the mother tree. The containers with the rootstock are brought near to the scions by means of a platform or scaffold built under each tree at a suitable height (Figure 1). The graft takes three months to heal, and during this period, they are severed from the mother tree in two stages. Before planting out in the field, the plants are kept in a cool place for another month. It thus requires a minimum of approximately sixteen months to produce a mango plant by this method.

It will be realized that the building of these scaffolds, the growing of rootstocks for such a long period, and the carrying out of the grafting operation on these elevated platforms make this method of grafting slow, cumbersome and expensive.

The scions required for grafting are selected branches, and the number of plants that can be produced is limited by the availability of such branches on existing mother trees. A large number of fully matured trees occupying a considerable acreage is thus required to produce plants in economic quantities by this method and any planning for production has to be carried out several years ahead.

On account of these drawbacks alternative methods have been investigated, and in many countries inarching has been replaced by chip, shield or patch budding. Within recent times veneer grafts have become popular in the United States of America (POPENOE, 1956).

In Trinidad, however, alternative methods have been tried with limited success, and on account of the very low percentage of takes there was no change over from the existing method of inarching.

Investigations were thus initiated to determine the cause of failure of methods reported to be successful in other countries. Several trials of budding and grafting were carried out using different stages of growth of stock and scion, and different wrapping material. After correcting some of the causes of failure, a fair percentage of takes was achieved by patch budding and terminal wedge grafts on one-year old stocks growing in the field, and side veneer grafts on four-month old stock growing in containers and in the field.

Figure 1. Julie mango tree with inarched grafts and scaffolding

0041-3216/2021/030226-231

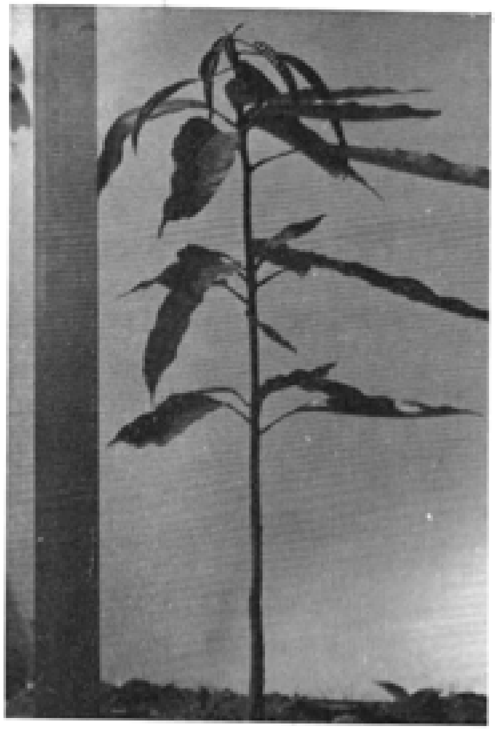


Figure 2. Four month old mango rootstock

With knowledge gained from these trials a new method has been devised for the propagation of mangoes—The 'T' Graft Method—which has the advantages of rapidity, low cost, and ease of production.

DESCRIPTION OF METHOD

The 'T' Graft Method consists of making a 'T' cut in the bark of the stock, and inserting between the wood and the bark a prepared terminal shoot. The scion is then tied firmly to the stock and the entire graft is wrapped with plastic tape.

Preparation of stock

Seeds of a vigorous variety of seedling mango are collected and sown in a germinating medium (cocopeat, sawdust etc.) and after sprouting they are removed to prepared nursery rows in the field. In Florida the hard seed covering is opened (LYNCH and MUSLARD, 1955) and the seed is separated from the husk before placing it in the germinating medium; this is done to reduce the period required for the seeds to sprout.

After four months the nursery seedlings, which should have attained a circumference of in. to 1 in. at 3/4 in. above ground level, may be grafted (Figure 2). This is the minimum size of stock on which a 'T' graft can be done with reasonable success.

Preparation of scion

The scions are selected from terminal shoots which have attained a growth of 3 to 4 in. and are at least 4 in. in circumference, with well matured growth on which terminal buds are swollen. The scion must always be slightly thinner than the stock. Thus, in selecting scions for grafting it is necessary to know the size of the stocks available.

Selected scions are defoliated 8 to 10 days before cutting off from the mother trees (Figure 3). This is done to allow the petiole stubs remaining on the shoot to drop off naturally, resulting in the formation of a protective seal at the paints of abscission. Scions used without this pretreatment have resulted in a high percentage of failures, as a result of fungal infection through the cut petiole.

A sloping cut is made to the scion starting in from the base of the terminal bud and extending downward to at least 1.5 in., ending with a point on the other side of the scion (Figure 4) .

Grafting

At a point at least 3 in. above ground level, a 'T' cut is made in the bark of the stock. The horizontal cut of the 'T' is made half way round the circumference of the stock, and the vertical cut is made 1.5 to 2 in. long. The bark at the top end of the vertical cut is lifted sideways and downwards extending to half way down the length of the cut. On the top side of the horizontal cut, at the point where the two cuts of the 'T' meet, a chip of bark is removed to facilitate a closer fit between stock and scion (Figure 5).

The prepared scion is inserted between the bark and wood of the stock, and pushed down along the vertical cut of the 'T' until the top end ofthe cut surface of the scion is in contact with the cut surface left on the stock where the bark was removed from the top of the horizontal cut.

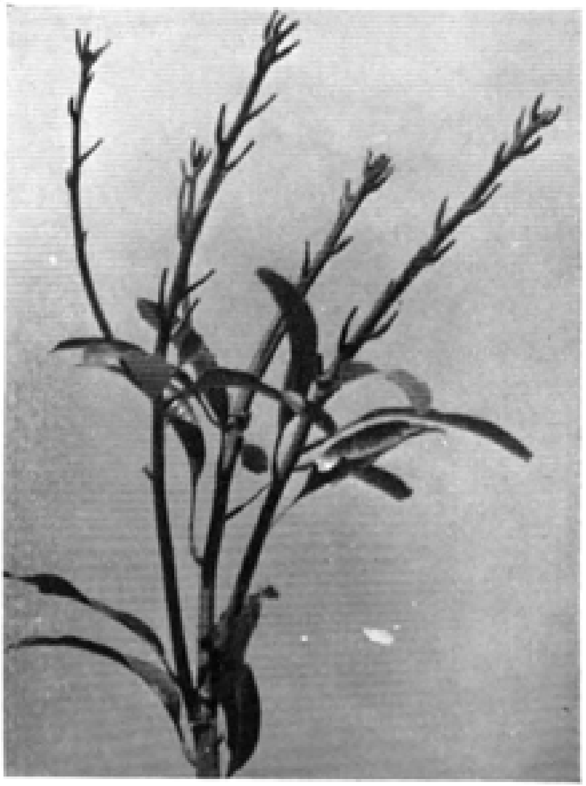


Figure 3. Julie mango branch trait defoliated terminal scions

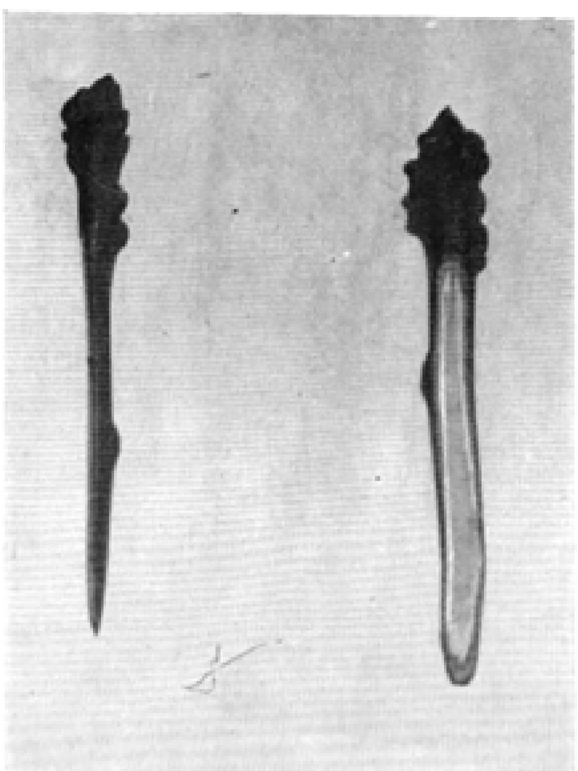


Figure 4. Scions prepared for grafting

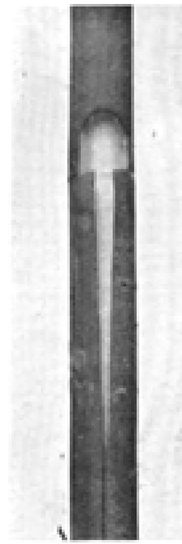


Figure 5. Rootstock with chip of bark removed above ‘T’ cut

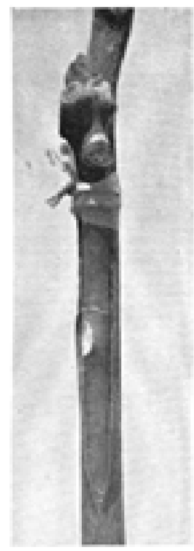


Figure 6. Scion tied to rootstock

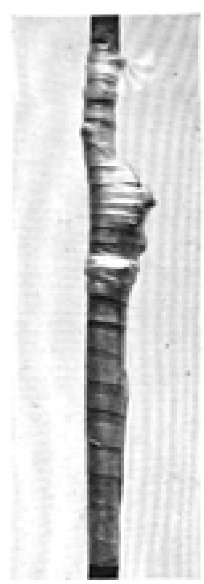


Figure 7. Scion wrapped with plastic tape

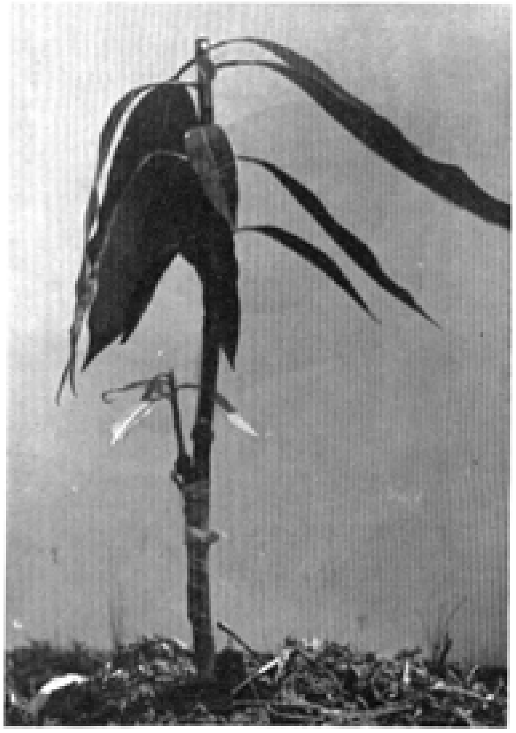


Figure 8. One month after grafting

Figure 10. Three months after grafting

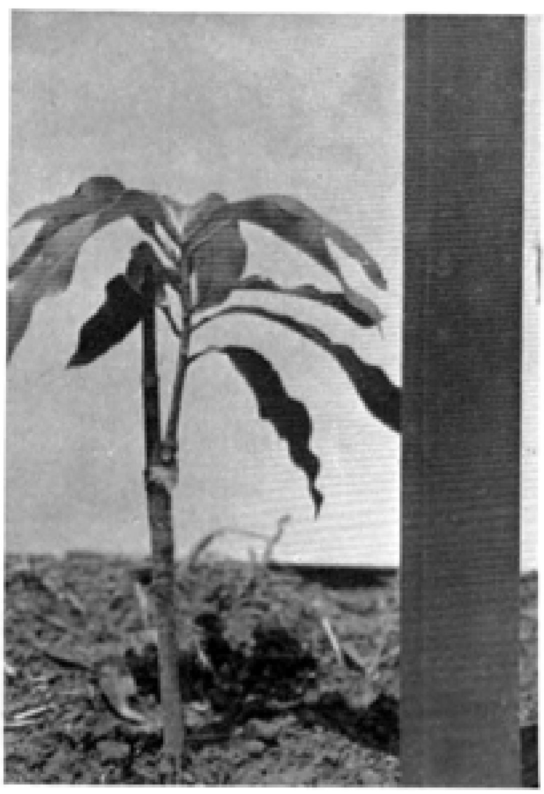


Figure 9. Two months after grafting

The scion is then tied firmly to the stock with raffia by making a knot near the region of the horizontal cut (Figure 6). The entire graft including the terminal bud is finally wrapped with resinite tape or polythene 0.0035 in. x 4 in. (Figure 7).

Over 80 per cent successful grafts have been obtained by the use of this method.

After-care

Twenty one days after grafting the wrapping material is removed from the terminal bud only, and about one third of the growth of the stock above the graft is cut back. The scion at this time is beginning to shoot from its terminal bud (Figure 8). After two months a fair amount of foliage is produced by the scion, and at this time the stock is cut back farther (Figure 9). At three end of the third month a final cut is made to the stock at the top end of the grafted region, and all wrapping material is removed. By this time the scion has grown and produced a crown of foliage large enough for the plant to be transplanted (Figure 10).

Figure 11. Lifted plants for transplanting

Lifting

The percentage of mortality in mangoes on lifting and transplanting is comparatively high. Trials carried out on lifting have shown that by lifting the plant in two stages, the percentage lost by this operation is reduced to a minimum. In the first stage, one month before lifting the plant, at a distance of 3 to 4 in. from the plant the soil is removed from one side to a depth of 8 to 10 in. and the tap root is severed. The soil is replaced, and the plant is given a dressing of sulphate of ammonia at the rate of 1 oz per plant. After the one-month period has elapsed the second stage of lifting the plant from the ground with a ball of earth is carried out. The ball of earth is wrapped with pieces of jute bagging material, and the plant is ready for immediate transplanting, or may be left in a cool place where it can be stored for weeks with a little watering (Figure II).

DISCUSSION

By the 'T' Graft Method a minimum of seven months to produce a fair sized plant is required. This is a saving in time of at least nine months when compared with the inarching method.

A grafter can complete at least 100 lateral grafts by this method in a working day as against 36 by Marching.

The cost of production by the 'T' Graft Method is estimated at 22c. per plant. The Marching method as carried out at St Augustine Station, a Governmental Agricultural Station for the propagation of plants in Trinidad, costs 95c. (B.W.I.) per plant—an appreciable difference. The cost of production for 1000 plants by both methods is given for comparison

below.

(a) By inarching method

	$ c.(B.W.I.)•
Seeds and bamboo pots	157.80
Preparation of soil, potting and watering	332.68
Scaffolding	293.30
Grafting, including untaping, cost of tape, twine and tar	174.39
Total	957.17

(b) By 'T' Graft Method

Seeds and preparation before planting	28.00
Preparation of land for planting	7.00
Planting, weeding and manuring	33.60
Grafting, including preparation of scions, untaping, cuttingback and cost of tape	51.25
Lifting	105.00
Total	224.85

*1 B.W.I. Dollar = 4s 2d

The above details of costs of production were prepared in January 1957 when the average rates for labour were as follows:

Men	— $3.00 per day
Women	— $2.70 per day
Boys	— $2.46 per day

Much of the success of the 'Lateral Bark Graft' depends on the stage of growth of the stock. In Florida, rootstocks two to three weeks old are used with good success in chip budding (LYNCH and MUSLARD, 1955). In the 'T' Graft, however, it is necessary to have the bark and wood of the stock well developed, but the plant must remain in an active state of growth. This is noticeable by a new flush of leaves or by cutting the bark when a distinct ooze of plant sap from the cut surface can be seen. At this stage the bark lifts easily.

The type of wrapping material used is important. Resinite CT-4 Clear Budding Tape (size 1 in. x 0.004 in.) and polythene of the same gauge have given excellent results as against raffia and waxed tape. Good results have also been reported with the use of resinite tape in the budding of cocoa (TOPPER, 1956).

There seems to be some difference in the rate of growth of different varieties of mangoes used as rockstocks at least in the nursery stage. Three varieties locally known as 'vert' , 'rose' and 'teen' were used as root stocks in these investigations. Of these 'rose' was the most vigorous and gave the best results on grafting. Further investigations are necessary to determine the most suitable rootstock.

SUMMARY

A new method—the 'T' Graft Method—of mango propagation is described. The method consists of making a 'T' cut in the bark of the stock and inserting between the bark and the wood a prepared scion from a terminal shoot.

The cost of producing plants by the new method is 23 percent of the cost by inarching. The output of plants is greater and the period required to produce a plant is less than half the time required by inarching.

ACKNOWLEDGEMENTS

My grateful thanks are due to Dr B. G. Montserin, Deputy Director of Agriculture (Research), for his encouragement and keen interest during the course of these investigations; to Mr St George Cooper, Senior Agricultural Officer, for helpful suggestions on reading the script and to Mr R. Dowlat for the skill displayed in carrying out the grafting trials.

(Received September 1957)

REFERENCES

LYNCH, S. J. and MUSLARD, M. J. (1955). 'Mangoes in Florida'. *Bull. Fla Dep. Agric.*20, 13

POPENOE, W. (1956). Tribute to Florida. *Cuba* 4, 321

TOPPER, B. F. (1956). *A New Method of Vegetative Propagation of Cocoa*. Department of Agriculture, Jamaica

Extracted from Volume 41, Number 3, 1964

Soil Surveys and Their Application in Tropical Agriculture

J. K. COULTER

Regional Research Centre, University of the West Indies, St Augustine

In a recent paper on soil surveys Kellogg (1962) stated ' I am persuaded that the failure of the British Groundnut Scheme in East Africa did more to get soil surveys accelerated in that continent than anything else'. Undoubtedly there is now a greater appreciation of the value of soil surveys for developing countries and the provision of aerial photographs and improved maps has made surveying quicker and more accurate. On the other hand greatly increased funds from national and international agencies and the fact that soil surveys have become fashionable have led to a much greater interest in this type of work. Soil surveys have the added attraction to aid-giving agencies of having a beginning and an end and the end—the brightly coloured soil maps—can be exhibited as a measure of achievement.

In many territories the impetus for soil surveys has arisen from the necessity to introduce new crops, to expand established ones or to define areas for new settlements. Quite frequently, areas for detailed soil mapping have been chosen by administrators or politicians and the soil surveyor has then been expected to find suitable soils within the boundaries defined by them. This has been termed 'turning soil scientists into pedological procurers' by Charter (1957). In recent years this situation has been improving as a result of the greatly increased tempo of soil surveys. This has relieved the soil surveyors from pressure for ad hoc surveys and has allowed them to spend more time on reconnaissance surveys. Thus the roles are being reversed and the position is being reached where the surveyor can outline areas of potential agricultural value for the administrator.

In view of the fact that soil surveys are covering increasing areas of tropical countries and that the demand for surveys continues to increase there is need for a critical appraisal of their role in improving tropical agriculture. In this paper attention is drawn to some aspects of soil surveys and their use which need further investigation in order that such surveys may realize their full potential in contributing to the improvement of tropical agriculture.

OBJECTIVES OF SOIL SURVEYS

When funds were severely restricted most soil surveys were undertaken for limited objectives such as those outlined above. Now that there is generally more money available there is a greater tendency for work to be undertaken for ill-defined objectives or to fulfil the purpose, often vaguely expressed, of making an inventory of the country's resources. There is, of course, no objection to making such an inventory since soil maps have many applications outside agriculture. Nevertheless some of the considerable sums of money being spent on soil surveys could be spent better on other aspects of soil research as, for example, in follow-up agronomic work. Often it would be of immense value, both to the donors and the recipients of soil survey funds, if both parties were to spend some time considering just how a soil survey could advance the development of agriculture in the particular country over say the next 20 years. As science is continuously adding to our knowledge of soils, particularly tropical soils, there can be no 'complete' or 'final' soil map. Thus whilst a soil survey must aim at bringing forth all the basic information possible about the soils in the area, it should also be oriented towards well-defined objectives. If the objectives are clearly defined then it is possible to make a logical decision on whether 'reconnaissance' or 'detailed' soil mapping will be the more appropriate.

Most tropical countries have a genuine need for a reconnaissance soil survey, on at least a broad scale, over the whole country. Such a survey is invaluable in an area where there is little agricultural development for it enables the experienced soil surveyor to delineate those areas, which are the most promising or the most

0041-3216/2021/030232-240

easily developed, for the range of crops to which the environment is suited. A reconnaissance soil survey is also very valuable for providing a framework into which subsequent detail can be fitted. On the other hand a reconnaissance soil survey is really of little value as a basis for improving agriculture in a long-settled agricultural area since the farmers themselves have already accumulated a large amount of information from their own experience. Although it might be suggested that such a survey could define the problems confronting agricultural improvement, the agricultural advisory service, if one exists, can define them much better. Thus detailed work will be required to provide soil knowledge of value under conditions of long-settled agriculture.

There is not always a clear distinction between reconnaissance surveys and detailed surveys, but perhaps the most suitable distinction is that given by Johnson (1962) for the U.S.A. There, detailed mapping involves the direct observation of all soil boundaries throughout their course whilst, in reconnaissance mapping, some of the lines are drawn on the basis of photo-interpretation or inference. In the U.S.A. three levels of intensity of detailed surveys are employed: high intensity surveys are made at mapping scales of 1:7 920 or 1:15 840; medium intensity surveys, in which the map entities tend to embrace somewhat broader ranges of slope, soil depth etc., are usually made at a mapping scale of 1:15840; low intensity surveys, for areas of relatively extensive soil use, are at mapping scales of 1:15 840 to 1:31 680. The scales of mapping for detailed soil surveys are not always indicated by other countries. In England detailed surveying is carried out on maps at a scale of 1:10 560 whilst in New Zealand detailed soil surveys are published at 1:31 680 (Pohlen 1962).

Ideally, tropical areas with dense agricultural settlement would require soil maps at least at the medium intensity level of the U.S.A. Achieving this degree of detail and accuracy, even in settled areas with limited roads, would be extremely time-consuming and often quite beyond the resources available. To achieve a similar degree of detail and accuracy in unsettled areas, particularly those under forest, is almost completely out of the question. That these factors are operative is shown by the fact that even the more detailed soil surveys in the tropics are really made by detailed reconnaissance methods.

It would be very useful to know the type of detail which should be aimed at when mapping at the larger scales. Obviously very detailed separations can be made on the basis of profile morphology and laboratory data but there are many instances where, under present management conditions, the various units have virtually the same fertility. In fact, many separations are possible which, from the point of view of soil fertility, are virtually meaningless in the present state of knowledge of tropical soils. This is not confined to tropical soils for Grissom (1961) has drawn attention to the general difficulty of selecting valid criteria for differentiating soils relative to land use. Exceptions to the above are found in the volcanic soils of the West Indies where relatively sharp boundaries, between soils of markedly different fertility, can occur.

A further point which should have bearing on decisions about undertaking detailed soil surveys is the state of development of the country. In terms of both their services and their resources virtually all tropical territories are underdeveloped though there are exceptions in the West Indies, for example, where some of the islands are relatively well developed in their resources, such as they are, but poorly developed in their services. The state of development of a country's services is a very important consideration, when deciding on the scope of detailed soil surveys, for there is little point in doing a detailed survey of a million acres if the country has the services to develop only 100 000 acres in the next 20 years.

The foregoing consideration thus suggests that whilst reconnaissance soil surveys in tropical countries can nearly always be justified, detailed surveys require close examination as to their purpose and their necessity. They are obviously valuable and indeed essential for irrigation schemes where their value rests on the fact that the major soil factors influencing irrigation agriculture are both known and mappable. They are possibly of value also in areas of intensive mono-culture, for example, of sugar-cane, but they have yet to prove their value for the general run of tropical agriculture, particularly, peasant agriculture.

SOIL CLASSIFICATION IN SOIL SURVEYS

It is of course possible to carry out a soil survey without classifying the mapped soils either in relation to one another or to soils in different areas. However, the value of the work is increased immeasurably if the soils can be placed in groups showing their inter-relationships. Not only is the subsequent value of the soil map enhanced but the surveyor is given the opportunity to contribute to an understanding of the soils in the region. However, a soil classification, to be really valuable, requires considerable comprehension of the soils involved and at the present time mapping of tropical soils is well ahead or the knowledge of their genesis and properties. Normally the type of classification adopted will depend on the amount and kind of information available but it is obvious that a classification based on the results of detailed mapping would be virtually useless in extensive reconnaissance surveys unless the amount of detailed mapping is very great.

Usually, in the tropics, the surveyor will use recognized principles for his classification since he is unlikely to have the time or the facilities to work out new ones. The most comprehensive soil classification is the '7th Approximation' (Soil Survey Staff 1960) but unfortunately the orders covering the tropical soils, particularly that on latosols, are the least comprehensive. At the lower categories the 7th Approximation is more detailed than most other systems of classification so that its use at the lower levels even in tropical soils, is possible. However, the principles governing the choice of the differentiae are defined only in rather general terms and whilst these differentiae may have appropriate significance under conditions in the U.S.A., they need not have the same significance in all tropical soils. There does not, in fact, appear to be any fully satisfactory method for classifying tropical soils at the lower levels at present. It might also be questioned whether the soil type, as presently defined, is the most appropriate basic unit for classification in tropical soils. There does not appear to be anything better in view at present but subsequent research may show that the parameters now defining soil types should be modified for tropical soils.

Padi soils are a special group of soils which, because of their intensive agriculture, require detailed mapping but which have received little attention from the classification point of view. For this reason the recent paper by Kanno (1962) on their classification is of interest. He points out that rice soils are the result of a combination of both natural and artificial soil forming factors; they not only inherit some of the characteristics of the soils from which they have been developed but waterlogging and complicated cultivation practices bring about chemical and physical changes in the profile which have to be taken into account in their classification. It is of interest that Kanno uses an ecological definition, i.e. growth of one or two crops per year, as the initial separation of rice soils. Subsequent divisions are made on the basis of gleying, drainage, type of clay mineral and texture. This classification would appear to have considerable value for fertility work on rice soils since most of the criteria used for differentiae are known to influence crop responses.

The soil surveyor in the tropics needs a classification at the higher categories when carrying out reconnaissance soil surveys and in these conditions some form of descending system only is possible since accurate data on the soils will not be available in large amounts. Such a system may be based on genetic factors as in the Russian classification (Ivanova 1956) or on pedogenetic processes as in those of Aubert and Duchaufour (1956), D'Hoore (1960) and Pohlen (1962). The latter states that, in New Zealand, the genetic classification is an attempt to interpret the soil in terms of soil processes as indicated by morphological, chemical, biological and other soil properties.

The descending type of classification has been used in the early days of soil survey and classification in many parts of the world and the U.S.A., Russia and Australia have all used a genetic approach. Both the U.S.A. and Australia have moved away from the emphasis on genetic criteria and in Russia, though the genetic approach is still regarded as the only approach to soil classification, there is considerable emphasis on the use to be made of soil profile data (Basinski 1959). Thus in the tropics, where soil studies are relatively limited, a genetic approach forms an excellent working hypothesis for studies of soil processes. In the future, when there is much more information from detailed field and laboratory studies, an ascending type of classification may become necessary.

In tropical areas there would appear to be considerable scope for the use of landscape analyses as a basis for reconnaissance mapping. Perhaps the best known landscape unit is the catena as defined by Milne (1935). This is a repeating unit formed on similar parent material and under the same climate, the pattern of soil development being the result of differential drainage as influenced by topography. The unit is in fact part of a toposequence.

An entirely different kind of toposequence is that on steep land where there is a pattern of eroding and accumulating phases in the landscape. Such a pattern is common in the volcanic soils of the West Indies and being very important from the fertility point of view, should be recognized in soil mapping.

In the volcanic islands of the West Indies and indeed elsewhere another sequence is found which is the result of the effect of increasing rainfall on the same parent material under similar drainage conditions. The resulting soils form a characteristic sequence from lower to higher elevations, of regosols through immature soils to kandoid and finally allophanoid latosolics.

This sequence, which might be regarded as another sort of catena and was in fact suggested as such by Milne, resembles the soil suite of New Zealand (Taylor and Pohlen 1962). It could be regarded as a pluviasequence.

Different parent materials will of course give different sequences but the pattern remains the same.

In older landscapes in the humid tropics, where the soils are thoroughly weathered and leached, the parent material exerts a profound influence and in granite country in Malaya, for example, a repeating pattern due to the different types of granite is found. The more basic rocks give soils with a higher clay content, the more acid, sandy soils. Although the pattern is not nearly so regular as in the toposequence and pluviasequence landscapes, a pattern which might be termed a geosequence can certainly be found.

In many parts of the world soils have formed under environments which are very different from those of the present day. In these, cycles of erosion and deposition can be distinguished and the term ‘K cycle’ has been introduced by Butler (1959) to describe the sequences which result from periodic phenomena. He points out that the difference in age of the surface in any locality is a prime cause for soil differences. In terms of ground surface relationships the periodic phenomena lead to the development of characteristic sequences which might be termed chronosequences.

These suggestions for the recognition of landscape units, with soils which appear to be dominated by one or other of the soil-forming processes, are merely put forward as an illustration of a way in which landscape analyses might be used for an understanding of the soil pattern and thus lead to more meaningful soil maps. A form of landscape analysis has, in fact, been used for the broad scale reconnaissance surveys by the Land Research and Regional Survey organization in Australia (Christian and Stewart 1953). They use ‘land systems’ as the unit of mapping and they define a land system, which is a composite of related units, as an area throughout which there is a recurring pattern of topography, soils and vegetation.

LAND USE CLASSIFICATION

In developing countries, a soil survey is a means to a very practical end, the end being some form of interpretative soil classification. Sometimes it is suggested that this should be left to the agriculturist or horticulturist but in fact, soil surveyors are in the better position to carry out land capability classification and interpretative soil groupings, since they have studied the soils in the field and have seen their variations and observed their management and fertility problems. Nevertheless in interpretative soil classification the soil surveyor in the tropics is often at a serious disadvantage for he is frequently relatively inexperienced or, if experienced, is so in a different environment. In addition, far less is known about the soils; and the difficulties in the tropics are summarized by Riecken and Smith’s statement (1949) that ‘The greater the body of knowledge about soil profiles of an area and the more complete the understanding of the functional relationship of the important soil properties to the soil-forming factors, the easier will be the task of establishing the basic soil profile units of the area. Moreover the decisions will be more satisfactory if the management requirements are known through research and experience’.

An interpretative soil classification may include the formulation of some kind of productivity rating, which is a prediction of the behaviour of the soil under a particular system of land management. The rating may be expressed as a percentage of the potential production of a particular crop growing on the soils recognized as best suited to it and under better than average management conditions. In the tropics it is extremely difficult to apply this type of approach, especially in peasant agriculture, since the management levels are generally so low that it is, in fact, almost impossible to get an accurate estimate of the potential yield of any particular crop. Thus in the West Indies it is very difficult to form an accurate estimate of the yield potential of most of the soils for food crops. With cash crops, for example, bananas and sugar-cane, it is easier since these are grown by a number of estates with high standards of management.

An alternative method is to use a rating such as the Store (1933) index whereby the soil is interpreted on the basis of its profile, texture and modifying factors. This approach can lead to difficulties also since the emphasis given to any one factor should vary from region to region. In temperate lands, with the necessity for mechanization, steep slopes are given a low rating whereas level soils, low in chemical fertility, are given a higher rating. In the tropics, however, steep slopes are quite suitable for many tree crops but the infertile level soils may be too expensive, in terms of fertilizers, to utilize for peasant agriculture. Moreover the limited knowledge of tropical soils makes it more difficult to apply such inductive methods.

Factors affecting productivity of tropical soils vary greatly from region to region. In the older weathered and leached soils, for example, detailed relationships in terms of soil fertility appear rather obscure and may perhaps depend on rather fine differences in the small amount of weatherable minerals. It would also appear that the amount of clay, even though the predominant clay mineral remains the same, is of great importance. In Malaya, soils formed on different types of granites show quite marked differences in their ability to grow crops even though all the soils appear equally weathered and leached. The more basic members give rise to soils with a higher clay content and possibly their ability to hold more moisture and retain more nutrients makes them more productive soils. Perhaps in such soils a good correlation between a single factor and overall soil fertility may be found. Soils with differing kinds of clay, differing base saturation and differing amounts of silts may present a much more complicated problem when correlating classification with fertility.

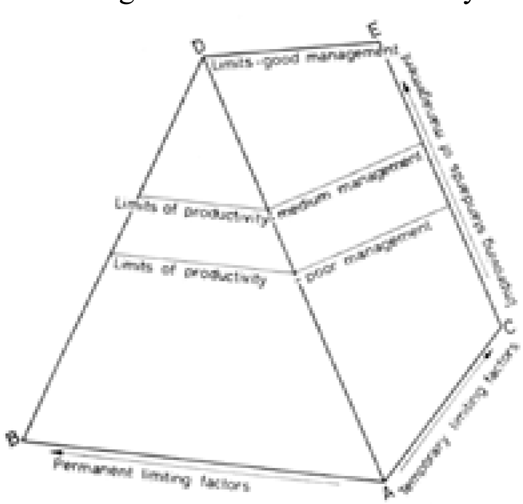


Figure 1. Influence of management standards on productivity ratings

In an attempt at interpretative soil classification soils cannot be considered in isolation, for good soils can 'carry' poor soils, i.e. make it worthwhile developing them in terms of services like roads etc. The 'good' soils alone may not justify developing an area but the 'good' soils together with the potential of the 'poor' soils may make it profitable.

In setting up land capability classifications in the tropics more attention should be given to management as a factor in calculating productivity ratings. The latter can vary very greatly depending on the type of management which is adopted. Soils under well-managed, adequately financed estate agriculture have the greatest potential. Soils with peasants organized into groups and working under close supervision, as for instance in some land development schemes, will have a lower potential and those under ordinary peasant agriculture will have the lowest potential of all.

The influence of any particular limiting factor will vary with the class of management. Steep slopes and rockiness, 'permanent' limiting factors, operate more or less equally against estates and peasants but low fertility, lack of drainage, or need for irrigation, 'temporary' limiting factors, reduce the potential productivity more for peasants than for estates. Figure 1 demonstrates these interactions in graphical form. 'Permanent' limiting factors, in increasing severity, are set out along AB. These comprise the seven land capability classes of Steele, Vernon and Hewitt (1954), running from Class I (A and B slopes of good soils) to Class VII (rock out-crops, river wash etc.). 'Temporary' limiting factors are set out along AC and increase in severity from low fertility through poor drainage to poor water supply. Management factors are set out along AD with the standard of management increasing from A to D, from peasant farmers to well managed highly capitalized estates. The slope of BD would vary with the kind of crop; it will be steepest for crops which have the highest response, to good management.

In illustrating the interactions controlling productivity, Figure 1 is of course highly stylized but there may be sufficient information on a number of the major crops on at least some soils to be able to give more precise meaning to the limits illustrated by the diagram.

It is unfortunate that the material for calculation of productivity ratings in tropical soils is generally extremely scanty, for soundly based ratings could be of immense advantage to countries which have very limited capital for development and which will or should wish to use it where it can produce the most benefit. In some ways the approach described by Visser (1952) in Holland, where increased productivity is estimated in terms of additional land, might be useful. Thus an increase in production of 25 per cent on an existing acre of agricultural land is equivalent to bringing into production a quarter of an acre of new land. It would appear that this approach would be particularly useful for such projects as rice irrigation schemes where improvement of the drainage and irrigation of existing land would often bring a bigger return on investment than the reclamation of new land. However, political considerations may be overriding and it may be considered better to have two farmers, both farming poorly, than to have one farming well and the other not at all.

Single factor soil maps are sometimes used as a method of interpretative classification. Such maps are usually based on a more complete survey of the area and their value depends on the particular factor and the extent of its dominance in the soil productivity. Certain single factor maps, such as those showing depth of peat or levels of salts, may be made in a primary survey; these are valuable, since they show a factor which is overwhelmingly dominant in the use of the land and they can be made more quickly.

In spite of the inherent difficulties in making land use recommendations for tropical soils, force of circumstances has led to many such recommendations by soil surveyors. However, large numbers of surveys are of such recent date, mostly post-1946, that generally there has not been time to test out the value of their assessments and, where the surveyed land has been developed, the soil surveyor has often long since gone elsewhere. Appraisal of these surveys in the light of subsequent agricultural development would be of great value.

SOIL SURVEYS AND SOIL FERTILITY

Although the past decade has seen very considerable development in soil surveys in the tropics, there has not been the same emphasis on the second or follow-up stage—studies on the fertility of the soils which have been mapped. This is, in fact, a more difficult and time-consuming phase than soil survey. It must be recognized that the final measure of soil fertility is the field experiment and that properly conducted field experiments form the soundest basis for productivity ratings and for studies on the chemical and physical factors controlling productivity. Furthermore fertilizer trials should be carried out even where there are no prospects, at present, of using fertilizers.

In the past much of the field experimental programme was carried out in experiment stations, where neither the fertility nor the management was representative of farmers' land. Only in recent years have field experiments on farmers' land become a recognized part of the research programme on soil fertility. Examples of such work are the experiments by Nye (1951) in West Africa and by Mukerjee (1960) in India. The approach to field experiments can take several forms. Where there is very little detailed information on the soil then probably the best technique is one such as that used by Mukerjee. In this, simple trials are laid down on sites selected at random, with one replicate per site, in an area of fairly homogeneous soils. The results can be analysed as replicates of one trial or split up into regions and analysed as groups. This type of experiment gives information on the overall fertilizer requirements of the region but gives little information on individual soils or on individual farmers' fields. Thus it might show that the use of fertilizers is profitable from the national standpoint but not necessarily so for the individual farmer. Furthermore this type of experiment is not suitable as a basis for material for plant and soil analyses. The advantage of this approach is that it is a fairly quick method of getting an overall picture of the fertilizer needs of a country and is thus of value when such a country is embarking on a fertilizer manufacture or subsidy policy. However, it is of limited value in regions where areas of homogeneous soils are small and changes in fertility abrupt.

Instead of selecting sites entirely at random they can be selected on the basis of some observation on the soil. Thus the sites for the large series of trials on phosphate responses of various crops carried out in the U.K. in 1941-46 and 1951-53 (Cooke 1956) were generally chosen on the basis of soil phosphate levels as determined by soil analyses. There are obvious advantages in such an approach but it is of limited application in the tropics since soil analysis is generally of little value for predicting fertilizer responses.

If soil maps are available the more useful approach is to use factorial experiments, carefully selecting the sites on the basis of an examination of the soil and its relation to the modal profile. The ability of the agronomist to recognize the soils is therefore very important. This is the approach now being used in the West Indies (Twvford and Coulter 1962). Factorial experiments are certainly the most useful, particularly if treatments are carried out at three levels, for it is thus possible to obtain response curves. Although primary attention will probably be given to nitrogen, phosphate and potash, there is very good reason to extend the factorial treatments to other factors amongst which plant density is probably one of the most important. Presented thus, experiments on farmers' fields appear deceptively simple but the very fact that they are difficult to arrange and manage has been the main reason preventing their much wider adoption. In the tropics there are all the difficulties inherent in dealing with poor farmers, small fields, poor protection against humans and stock, and the fact that the farmer cannot really spare land from which he may get no return. Perhaps the most important factor of all is management, and many experiments are useless because the standards of management are such that poor management completely overshadows any fertilizer effect. In order to have a justified basis of comparison of the productivity and responses of different soils it is essential that all trials have near uniformity of management in terms of cultivation, plant density, weed control, pest control, time of planting etc. Though such standards may be quite far removed from those of the farmer it is still essential to have them.

The number of experiments which can be carried out depends on a host of factors and there will never be enough experiments to take care of all the soils involved. Some of the trials will inevitably be lost so that extra trials need to be put down. However, if too many come to fruition the agronomist will be unable to deal with them and it is only after considerable experience of the particular conditions that he will be in a position to judge accurately the appropriate number of field trials to use in the area.

Yates (1952) discusses the returns to be expected from experimentation and points out that there may be a case for not carrying out the full amount of experimentation on one particular line that can be justified on economic grounds since the returns on the last few incremental steps are relatively small and it may be possible to use such experimental resources more effectively on other problems. He goes on to point out the advantages to be gained from coordinated series of modern well-designed factorial experiments, quoting sugar beet as an example. The issues raised in his paper are very important for experimentation in the tropics but they appear often to be ignored. The literature suggests that there are far too many experiments, mostly carried out on experimental stations, which are designed to take care of the last few incremental steps which he mentions. If his suggestions were accepted it could mean that experimental stations in the tropics would have a limited life for experimental work on soil fertility.

The information to be gained from a well-planned series of field experiments goes far beyond the results on fertilizer response for the particular crop and the particular soil. The experiments can supply the material for the study of correlations of nutrient uptake, soil analyses and fertilizer response. By carrying out pot experiments on the same soils, correlations between pot results and field results can be obtained. Spurious results in the field, important elements left out of the trial or the presence of toxic substances may be shown up by pot trials. Fertilizer trials are also the basis for correlations between soil classification and soil fertility. These considerations suggest then that the maximum amount of information from field experiments can only be obtained by a team approach and it is this which is so often lacking in the tropics. It scarcely needs emphasizing that one of the greatest advantages to be obtained by this approach will be the accumulation of a mass of background information essential for a better understanding of tropical soils.

Such basic information provides a possibility of extrapolating the results for a particular crop on a particular soil to other soils for the same crop. However, it would also be of great value if the results from a particular crop on one soil could be extrapolated to other crops on the same soil. The knowledge of the physiology of nutrition of tropical crops is at the moment too scanty for this to have much promise. Obviously tropical crops have greatly different requirements for individual nutrients but it is difficult to answer the question as to whether nutrients available to one species are unavailable to another. Information on this point is very limited but the paper by Nye and Foster (1956) on the uptake of ^{32}P suggests that there are no differences in the availability of soil phosphorus for the different species. If this is generally true then the ability of one species to take up much more of a particular nutrient from a given soil than another species may be due to root distribution and the volume of soil explored by the roots and the rate of uptake at a given activity.

In conclusion therefore it may be stated that, in the tropics, progress in soil mapping is already far ahead of the progress in gathering knowledge of soil fertility. The gap is likely to widen, since for any particular area soil mapping can be a short term project whereas fertility studies are essentially long term. Thus soil surveys should not be carried out in isolation in the tropics; they should be regarded as a part of the whole project for studying fertility of tropical soils.

ACKNOWLEDGEMENTS

The helpful comments of Messrs D. M. Carroll, J. Stark and I. T. Twyford are gratefully acknowledged.

(Received July 1963)

REFERENCES

AUBERT, G. and DUCHAUFOUR, P.(1956). 'Projet de classification des sols'. *6th Int. Congr. Soil Sri.* E, 597-604

BASINSKI. J. J. (1959). 'The Russian approach to soil classification and its recent development'. *J. Soil Sci.* 10, 14-26

BUTTLER, B. E.(1959). 'Periodic henomena in landscapes as a basis for soil studies.' *Soil Publication* No.14. C.S.I.R.O.: Melbourne, Australia

CHARTER, C. F. (1957). 'The aims and objects of tropical soil surveys' . *Soils & Fert.* 20, 127-128

CHRISTIAN, C. S. and STEWART, G. A. (1953). 'General report on survey of Katherine Darwin Region (1946).' *Land Research Series No.1*, C.S.I.R.O.: Melbourne

COOKE, G. W. (1956). 'Field experiments on phosphate fertilisers. A joint investigation.' *J. Agric. Sci.* 48, 74-103

D'HOORE, J. (1960). 'Soils Map of Africa', 3rd draft. *Sols Africains*, 5, 55-64

GIBBONS, F. R. (1961). 'Some misconceptions about what soil surveys can do.' *J. Soil Sci.* 12, 96-1(X)

IVANOVA, E. N. (1956). 'Essai de classification generale des sols'. *6th Int. Congr. Soil Sci.* E, 387-394

JOHNSON, W. M. (1962). 'Principles of soil classification and mapping in the United States.' *Trans. Joint Meet. Comm. IV & V Int. Soc. Soil Sci., New Zealand*, 522-527

KELLOGG, C. E. (1962). 'Soil surveys for use.' *Trans. Joint Meet. Comm. IV & V Int. Soc. Soil Sci., New Zealand*, 529-535

KANNO, I. (1962). 'A new classification system of rice soils in Japan'. *Trans. Joint Meet.Comm. IV & V Int. Soc. Soil Sci., New Zealand*, 617-624

MUKERJEE, H. N. (1960). 'Realistic determination of nutrient requirements of soils through extensive random simple experiments on farmers' fields' . *7th Int. Congr. Soil Sci.* 3, 112-121

MILNE, G. (1935). 'Some suggested units of classification and mapping, particularly for East African soils'. *Soil Research*, 4, 183-198

NYE, P. H. (1951). 'Studies on the fertility of Gold Coast soils. Pt I. General account of the experiments'. *Emp. J. exp. Agric.* 19, 217-223

NYE, P. H . and FOSTER, W. N. M. (1956). 'Do plants vary in their ability to utilize less readily available soil phosphate?' *6th Int. Congr. Soil Sci.* D, 257- 262

POHLEN, I. J. (1962). 'Soil classification in New Zealand'. *Trans. Joint .Meet. Comm. IV & V Int. Soc. Soil Sci., New Zealand*, 440-452

RIECKEN, F. F. and SMITH, G. D. (1949). 'Lower categories of soil classification: family, series, type and phase'. *Soil Sci*. 67, 107- 115

Soil Survey Staff. (1960). 'Soil Classification. A Comprehmsive System.' *7th Approximation*. U.S. Government Printing Office, Washington . D.C. 265 pp .

STEELE, J. G., VERNON, K. C. and HEWITT C.W. (1954). 'A capability grouping of the soils of Jamaica'. *5th Int. Congr. Soil Sci*. 3, 402-406

STORIE, R. E. (1933). 'An index for rating the agricultural value of soils'. *Bull. Calif. Agric. Exp. Sta . No. 556*, 44 pp.

TAYLOR, N. H. and POHLEN, I. J. (1962). 'Soil Survey method' *N.Z. Soil Bur. Bull. No. 25*; Department of Scientific & Industrial Research. Xew Zealand

TWYFORD, I. T. and COULTER, J. K. (1962). 'Soil capability assessment in the West Indies'. *Trans. Joint Meet. Comm. IV & V Int. Soc. Soil Sci., New Zealand*, 161- 163

VISSER, W. C. (1952). ' Soil scienc in the Nethcrlands. Agriculture'. *Soil Sci*. 74, 1-13

YATES, F. (1952). 'Principles governing the amount of experimentation in developmental work'. *Nature, Lond.* 170, 13 140

Extracted from Volume 45, Number 1, 1968

Two Tick-borne Diseases Affecting Exotic Cattle Introduced into Trinidad

H. E. WILLIAMS
Faculty of Agriculture, University of the West Indies, Trinidad, W.I.
and
F. O. GONZALEZ
Ministry of Agriculture, Trinidad & Tobago, W.I.

Several West Indian territories, served by the University of the West Indies, have embarked on the large-scale importation of dairy cattle from North America with a view to developing dairy industries. Stimulus for this development has come from a decline in the value of the traditional export crops and the apparent success of tropical Puerto Rico in creating a dairy industry with exotic cattle. Two major factors contributing to the Puerto Rican achievement seem to be the provision of improved nutrition and an environment free of cattle-fever ticks. Unlike Puerto Rico, Trinidad and other West Indian islands are infested with *Boophilus* ticks and, in Trinidad, introduced cattle have suffered an illness characterized by fever, anaemia, jaundice and sometimes death, occurring about two to six weeks after the animals were put on tick-infested pastures. Both bovine *Babesia*sis and bovine anaplasmosis have been recorded in Trinidad, and Boophilus ticks are reported vectors of both. Indeed, both diseases may occur simultaneously in the same animal.

In view of the virtual absence of laboratory support since heavy importations have been started, and the low incidence of red water (haemoglobinuria) as a clinical symptom, the cause of this early illness has not been determined. The present study, of which this is an interim report, was undertaken to determine the cause(s) of the illness, the sequence of infections, and the possibility of drug prophylaxis. Chlortetracycline, as Aurofac, was selected in this last connection because of its reported babesicidal (JANSEN, 1953) and Anaplasma-inhibiting actions and in view of its adaptability to administration through feed.

MATERIALS AND METHODS

Cattle

The animals were all Holstein heifers imported into Trinidad from Canada. It should be borne in mind that the cattle were imported by the Government in connection with a dairy development programme and not for experimentation with tick-borne diseases: hence, no procedure could be imposed that might jeopardize the lives of the animals. Management consisted of day and night grazing with housing during part or most of the heat of the day. Rectal temperatures were recorded in the morning after the animals were housed and rested for a while. While housed, both concentrates and fodder were fed. Animals with heavy coats were clipped.

Blood samples

Cattle were bled from the jugular vein, about 5 ml of blood being collected in a phial containing 0.15 ml of potassium oxalate, ammonium oxalate, and water, in the proportion 4 + 6 + 90 per cent, respectively (solutes dried to crystals in an oven before use). Blood samples were stored at 4°C and were used for haemoglobin estimations and preparation of blood smears.

Haemoglobin estimations

The Haden—Hausser haemoglobinometer was used; haemoglobin was estimated by the acid haematin method (with 0.1N hydrochloric acid). The result was read in 15 minutes and the reading augmented by three percent.

Blood smears

Thin blood smears were prepared and stored or stained with Wright's stain. It was found that smears made with a cover slip narrower than the glass slide, leaving a margin along both edges and terminating in a series of filaments, were a decided advantage. Smears were examined under oil immersion.

EXPERIMENTAL PROCEDURE

In trials 4 and 5, each shipment was divided into pairs of animals using similarity of age as the only

0041-3216/2021/030241-247

factor for pairing [trials 1 to 3 (WILLIAMS, 1966) are not reported here]. The cattle were exposed to ticks, at pasture, and the elder of each pair, presumably the more susceptible to tick-borne fevers, fed a chlortetracycline (Aurofac, Cyanamid)-medicated feed while the younger was used as an unmedicated control.

Trial 4

Nineteen heifers at Centeno were treated with the antibiotic and a further 18 served as controls. The animals were an average of 13.7 months (range 11 to 20 months) old and arrived by air on 2 and 4 November 1965, but all were assumed to have been imported on 4 November. The treated heifers received 10 mg of chlortetracycline per pound of body weight daily from the fifth to the sixteenth day inclusive after both groups went on pasture.

Trial 5

Twenty two heifers at St Joseph were treated with the antibiotic and 21 served as controls. The animals were an average of 11.2 months (range eight to 17 months) old. The treated heifers received 20 mg of chlortetracycline per pound of body weight daily, starting on the day before both groups went on pasture and continuing for a total of 22 days.

In the absence of any critical data for Trinidad and bearing in mind the purpose of the importations, two criteria were selected to signify illness and the need for mandatory treatment in both the feed-medicated and control groups. They were two consecutive morning rectal temperatures of 104.0°F or more from the eighth day on pasture: or suppression of appetite and a rectal temperature of 103.0°F or more from the eighth day on pasture. The interval between first going on pasture and the fulfilment of either criterion was taken as the clinical incubation period.

The mandatory treatment of animals which sickened in trials 4 and 5 was injected with tetracycline (Achromycin, Cyanamid) or oxytetracycline (Liquamycin-100,Pfizer) by intramuscular route and with phenamidine isethionate (May and Baker), subcutaneously, when haemoglobinuria was observed. This treatment was, in fact, customary for such animals at this stage. Blood transfusions were given in severe illnesses while disodium arsono-acetate (Robacyl, Farbenfabriken Bayer AG), vitamin B complex with liver extract (Combex, Parke, Davis and Co.), and several commercial forms of injectable iron were used in supporting roles.

RESULTS

Trial 4

An estimate was made each day of the medicated feed and unmedicated feed (fed at the rate of ¼ lb feed for every 50 lb of liveweight) which was not consumed. Eleven head on medicated feed failed to take up a total of approximately 106¼ lb of feed; refusal ranged from 2½ lb on one day to 28½ lb over seven days. In contrast, only one control animal rejected 4¾ lb of feed over three days. Medicated feed was substituted for unmedicated from the fifth to the sixteenth day inclusive.

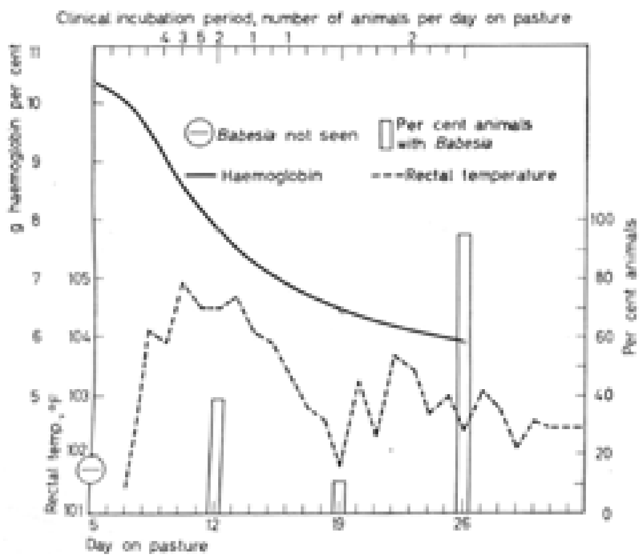


Figure 1(a)

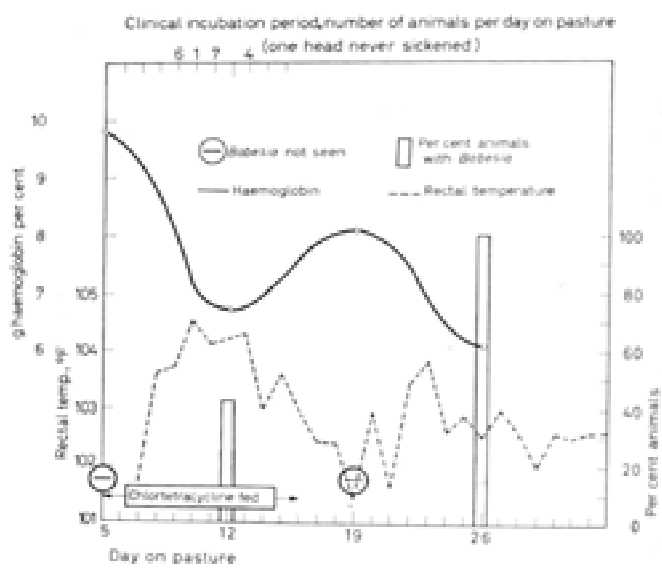


Figure 1(b)

Figures 1(a) and 1(b). The relationship between mean daily rectal temperatures, mean weekly haemoglobin levels, clinical incubation periods, weekly percentage of animals in which *Babesia* could be found in blood smears, chlortetracycline (Aurofac) medication, and lapse of time from initial exposure to pasture ticks in 18 control animals [Figure 1(a)] and 19 feed-medicated (Aurofac) animals [Figure 1(b)].The animals ranged from 11 to 20 months of age with a mean of 13.7 months.

However, none was rejected until the eighth day. Nine of the feed-medicated group refused some feed for one to two days after being returned to unmedicated feed.

Figures 1 (a) (unmedicated control group) and I (b) (medicated group) present the mean daily rectal temperatures, mean weekly haemoglobin levels, clinical incubation periods, and the weekly percentage of animals with blood parasites. Both groups exhibited a di-phasic febrile response. In both groups the mean haemoglobin was normal on the fifth day but was sub-normal (less than 8.7 g per 100 ml of blood) one week later in both groups. In the feed-medicated group [Figure 1 (b)], however, the mean haemoglobin rose appreciably to 8.08 g per cent on the third week (the nineteenth day) before again declining. The mean clinical incubation period was 9.2 days in the controls [Figure 1 (a)] and 10.7 days in the feed-medicated group [Figure 1 (b)]. The only blood parasites observed were *Babesia* spp. None was seen in either group on the fifth day, but seven days later seven head (38.8 per cent) of the controls and eight head (42.1 per cent) of the feed medicated group exhibited *Babesia* organisms. By the nineteenth day, two head (11.1 per cent) of the control group showed the organisms while none was seen in the feed-medicated group. The incidence again rose on the twenty sixth day, the organisms being found in 17 head (94.4 per cent) of the controls and 19 head (100.0 per cent) of the feed-medicated group. The earliest detection of *Babesia* was on the eleventh day on pasture in two medicated heifers and one control. Of 17 of the control animals which were bled on the day they fulfilled one of the criteria denoting illness and before treatment was given, one showed *Babesia* organisms, three were doubtful, and in 13 no organisms were observed. One animal only in the trial, the oldest (20 months) and in the feed-medicated group, was observed to have haemoglobinuria (on the thirteenth day) ; it was treated with phenamidine but died on the twenty sixth day. Altogether, of the 37 animals in the trial, *Babesia* organisms were seen in 36.

Trial 5

Between days 0 (day of importation into Trinidad) and one, 18 head on medicated feed rejected part of it as compared with ten in the control group. This was interpreted as being a general adjustment problem to a newly experienced Trinidad ration, together with a dislike of the high level of Aurofac. On the third day and thereafter the medicated feed (originally fed at the rate of lb feed for every 50 lb of liveweight) was mixed with an equal part of unmedicated feed. Consumption of medicated feed then became satisfactory but, generally, the animals had to be kept standing before the feed for three to four hours.

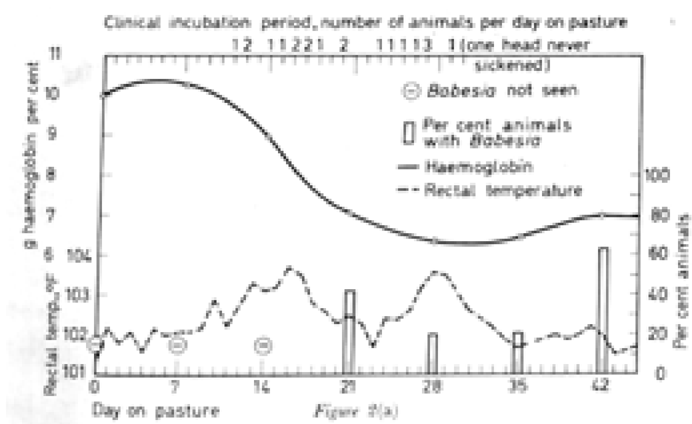


Figure 2(a)

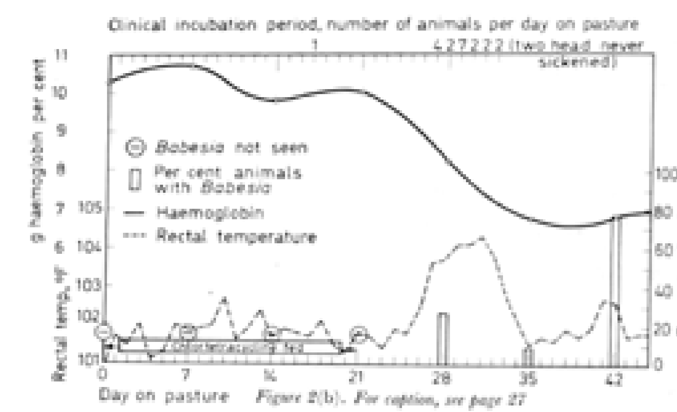


Figure 2(b)

Figures 2(a) and 2(b). The relationship between mean daily rectal temperatures, mean weekly haemoglobin levels, clinical incubation periods, weekly percentage of animals in which *Babesia* could be found in blood smears, chlortetracycline (Aurofac) medication, and lapse of time from initial exposure to pasture licks in 21 control animals [Figure 2(a)] and 22 feed-medicated (Aurofac) animals [Figure 2(b)]. The animals ranged from eight to a mean of 11.2 months.

Figures 2 (a) and 2 (b) present the same data as are recorded in Figures 1 (a) and 1 (b). The control group Figure 2 (a) displayed a di-phasic febrile response. In contrast, the feed-medicated group [Figure 2 (b)] showed a mono-phasic febrile reaction. In both groups the mean haemoglobin was normal until the fifteenth day when that of the control group became sub normal. The mean haemoglobin of the feed-medicated group, however, maintained normal levels until the twenty seventh day when it became sub-normal. The mean clinical incubation period was 19.8 days in the controls and 28.5 days in the feed-medicated group. The only blood parasites observed were *Babesia* spp. None was seen in either group on days 0 (the day of importation into Trinidad), seven or 14. However, on the twenty first day, eight head (42.1 per cent) of the controls [Figure 2 (a)] exhibited *Babesia* organisms. The incidence in this group on the twenty eighth, thirty fifth and forty second days was four head (21.0 per cent), four head and 12 head (63.1 per cent), respectively. The first organisms to be seen in blood from the medicated group [Figure 2 (b)] appeared on the twenty eighth day when six head (27.2 per cent) were found infected.

The incidence in this group on the thirty fifth and forty second days was two head (9.0 per cent) and 17 head (77.2 per cent), respectively. Of 18 of the control animals which were bled on the day they met one of the criteria denoting illness and before treatment was given, five showed *Babesia* organisms (one animal as soon as the sixteenth day on pasture, the earliest detection in the trial), one was doubtful, and in 12 no organisms were observed. Two animals died, both of which were in the control group. One (No. 232) died on the seventeenth day and the lesions, inclusive of haemoglobinuria in the bladder, were consistent with *Babesia*sis. The other (No. 207) died on the twentieth day when *Babesia* were present. Figure 3 shows the protracted anaemia which occurred in these two groups of animals. Of 42 head in the trial of which all slides had been examined up to the forty second day, 35 showed *Babesia*, organisms could not be found in six, and one was doubtful; the last mentioned was the fatality on the 17th day which was considered to be a victim of *Babesia*sis. Haemoglobinuria was observed twice in this trial, in one control animal on the 28th day and in one feed-medicated animal on the 30th day.

Figure 4 presents, for a selected animal (No. 146) from the control group of trial 5, the same data as recorded in Figures 1 and 2. It will be noted that, although *Babesia* were present and anaemia occurred, the animal met neither criterion of illness and, as a result, was not regarded as ever having sickened and was never treated within the first 42 days under discussion.

The surviving animals comprising this trial were kept under occasional observation for several months after the first 42 days reported on above.

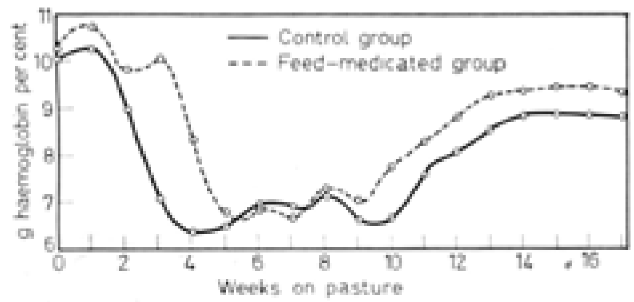


Figure 3. The relationship between mean haemoglobin levels and lapse of time from initial exposure to pasture ticks in the medicated and control groups of heifers in trial 5

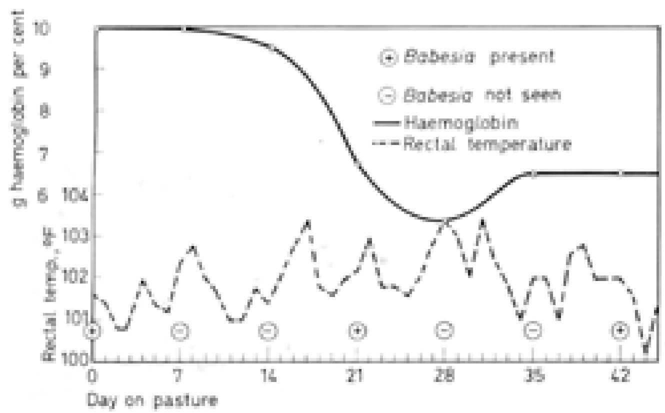


Figure 4. The relationship between daily rectal temperatures, mean weekly haemoglobin levels, weekly examinations in which *Babesia* could be found in blood smears, and lapse of time from initial exposure to pasture ticks in heifer No. 146, 11 months of age and from the control group of trial 5

During the sixth month after importation, haemoglobinuria was observed in one animal but no blood sample was submitted. During the sixth and seventh months after importation, ten cases of anaplasmosis were diagnosed by the examination of blood smears; an eleventh case of anaplasmosis occurred during the ninth month after the herd had been imported. Other cases of both diseases may have occurred but passed unnoticed. In all, 11 animals or 26.8 per cent of the survivors suffered infection with Anaplasma after a mean incubation period of seven months; five head were from the control group and six from the medicated.

***Babesia* spp.**

The organism mainly or entirely involved was a 'large' *Babesia* usually occurring centrally in red blood cells. The form most frequently seen had a central vacuole surrounded by a ring of blue-staining cytoplasm containing a red-staining nucleus at one point on the periphery. Occasionally, large, paired, oval or pear-shaped organisms almost the diameter of the red blood cell and at an acute angle, were seen. The agent was tentatively identified as *Babesia bigemina*.

Anaplasma slip.

The cases of anaplasmosis, seen six to nine months after importation, were attributed to the species *Anaplasma marginale*. It is interesting to note that Howell Jolly bodies were commonly seen, but rarely in excess of one per cent of the red blood cells. In trial 5, they were seen in the blood of several animals drawn on the day of arrival in Trinidad.

DISCUSSION

Trials 1 to 3 (WILLIAMS, 1966) and 4 to 5, reported here, were completed, in all other respects, before circumstances permitted the examination of any blood smears.

According to HENNING (1956) the incubation period of bovine *Babesia*sis or piroplasmosis is eight to 15 days, while that of anaplasmosis is 14 to 40 days after artificial infection and 50 to 100 days or more following natural infection. Lotze and Mott, according to RISTIC (1960), eliminated the incubation period of anaplasmosis by using large quantities of heavily parasitized blood as the inoculum; it is not unreasonable to suppose that the degree of tick infestation and tick infection may also affect the duration of incubation. Several authors have pointed out that where both diseases are present, *Babesia*sis occurs first followed by anaplasmosis which appears as a suspected relapse to *Babesia*sis.

The relatively low incidence of haemoglobinuria in the field amongst recent imports into Trinidad has been somewhat confusing. In the present study, three of 80 head (3.7 per cent) were seen with red water, whereas the organisms causing red water (*Babesia*) have been observed in the blood of 71 head (88.7 per cent). The low incidence of the red water symptom may have been due to the fact that all of the cattle were yearlings or younger with a mean age of 12.4 months. Some clinicians have apparently treated this early illness after importation almost exclusively with tetracycline drugs but age resistance may, in part, have been interpreted as a therapeutic response. Younger animals have, in fact, predominated in the imports. Indeed, one unpublished earlier report states that of 796 head of cattle imported since 1962, 648 (81.4 per cent) were 16 months of age or younger and that mortality from anaplasmosis was 2.1 per cent ; the remaining 148 animals were over 16 months of age and mortality from anaplasmosis was 12.8 per cent.

Davies et al. (1958) and others have noted the lack of obvious correlation between changes in body temperature and the development of *Babesia* infection. In our study, of a total of 35 control animals in trials 4 and 5 examined on the day they met one of the criteria signifying illness, only in six (17.1 per cent) were *Babesia* organisms seen in blood smears. It should be remembered too that although animal No. 146 (Figure 4) showed organisms and was decidedly anaemic it did not qualify for treatment on the basis of its body temperature, while animal No. 232 died with red water in its bladder but only doubtful *Babesia* structures were observed in its blood. Finally, it should be borne in mind that Howell—Jolly bodies, frequent concomitants of anaemia, may confuse the diagnosis of anaplasmosis.

Both Figures 1 (a) and 2 (a), presenting data derived from control groups, suggest a di-phasic disease as regards body temperature and parasitaemia. In BARNETT's (1965) experience, when recrudescence occurred in the intact animal the parasitaemia was normally very slight and no clinical response was invoked. Figure 4 suggests that *Babesia*sis may be diphasic in the untreated, intact, susceptible animal.

Ryley (1964) found that each of three sparingly soluble derivatives of quinuronium prevented clinical red water developing in splenectomized calves from intravenous challenge with *B. divergens* three months later; in one animal, although clinical signs of infection were absent, infection and premunition occurred.

In trial 4 it would appear that chlortetracycline at the rate of 10.0 mg/lb body weight, given by feed from the fifth to the sixteenth day inclusive after going on pasture, was insufficient to control the infection, but Figures 1 (a) and 2 (a) suggest that it counteracted, temporarily, the anaemia and reduced parasitaemia on day 19. In trial 5 chlortetracycline at the rate of 20.0 mg/lb body weight, given by feed from the day before going on pasture to the twenty first day on pasture, appears to have deferred fever, parasitaemia and anaemia for as long as it was given to the animals [Figures 2 (a) and (b)]. If, at the withdrawal of chlortetracycline on the twenty first day, ticks of all ages are present on the animals illness may be expected as early as six days later. JANSEN (1953) found that Aureomycin (chlortetracycline) had a babesicidal action against B. equi in a splenectomized donkey. By using repeated intravenous injections of the drug at the rate of 16.5 mg/lb body weight the animal recovered, relapsed, was treated again, and developed an immunity. According to WOOLFE (1962), Brownlie found chlortetracycline in large doses effective against feline piroplasmosis. Beveridge, according to JOYNER et al. (1963), found chlortetracycline inactive at 5 mg/kg body weight daily for five days against B. rodhaini in mice, while Taylor is reported to have found the antibiotic Stylomycin efficacious.

Our study confirms an early report of the Department of Agriculture, Trinidad (1910) that attributed illness and mortality in cattle within the first few weeks of importation to Texas Fever or *Babesia*sis. (It is interesting to note that *Anaplasma marginate* was recognized as an entirely new pathogen in 1910 in South Africa.) Aurofac may lend itself, through manipulation of dosage and time of administration, to a therapeutic or prophylactic role in *Babesia*sis, allowing premunition to ensue and having the decided advantage of application by mouth with the feed. However, our study also sheds light on a second or later haemolytic crisis in such animals, which may be caused by *Anaplasma marginate* or *Babesia*. It is possible that medication with the tetracycline drugs, by mouth and injection, during these trials may have served to extend the period of incubation of anaplasmosis or to avert early infection. In fact, chlortetracycline is of value in the treatment of anaplasmosis. Hence, in the later illness, when it appears that one or other or both of the causative organisms may be legitimately suspected, it or Aurofac may be particularly useful.

SUMMARY

Babesia spp. appear to be responsible for a febrile disease of exotic cattle associated with marked anaemia, occasional haemoglobinuria, and sometimes death, occurring about two to six weeks after importation and introduction to tick-infested pastures. This confirms a record made 58 years earlier in Trinidad. The organisms have been found on two farms.

Anaplasma marginale infection and ‘relapses’ to *Babesia* seem to be responsible for a later (six to nine months after importation) haemolytic crisis or crises.

Chlortetracycline, as Aurofac in the feed, will apparently prevent or control babesiasis in cattle in Trinidad, but further work is needed to ascertain its application either in a prophylactic or therapeutic role.

Fever, noted from the eighth day on pasture from daily rectal temperatures taken in the morning, is not entirely reliable for the detection of *Babesia*sis in newly imported yearling cattle, but it is probably the most useful symptom (together with a blanching of the mucous membranes) for the clinician. A single thin blood smear made when the animal sickens is, apparently, not reliable for diagnosis, because in this study it only revealed the causal organism in six head (17.1 per cent) of 35 untreated control cattle. Red water or haemoglobinuria seems to be even less reliable.

ACKNOWLEDGEMENTS

The authors are grateful to the Minister of Agriculture and Chief Technical Officer (Agriculture), Trinidad and Tobago, for the opportunity to carry out this study which was made mainly on Government-owned cattle and at Government livestock stations. Both Professor P. Mahadevan and Mr S. J. Cowlishaw are thanked for their generous assistance. The valuable cooperation of Miss J. Alli and Messrs G. Raj Kumar, L. Khan, J. Khan and C. Jones is also acknowledged.

(Received March 1967)

REFERENCES

BARNETT, S. F. (1965). 'The chemotherapy of *Babesia* bigemina infection in cattle' . *Res. vet. Sci.* 6, 410

DAVIES, S. F. M., JOYNER, L. P. and KENDALL, S. B. (1958). 'Studies on *Babesia* divergens (M'Fadyean and Stockman, 1911)'. *Ann. trop. Med. Parasit.* 52, 209

Department of Agriculture, Trinidad (1910). Annual Report for 1910, p 31. Port of Spain: Government Printing Office

HENNING, M. W. (1956). *Animal Diseases in South Africa*, 3rd ed., pp 550 and 574. South Africa: Central News Agency Ltd.

JANSEN, 13. C. (1953). 'The parasiticidal effect of Aureomycin (Lederle) on *Babesia equi*(Laveran, 1899) in splenectomized donkeys'. *Onderstepoort J. vet. Res.* 26, 177-178

JOYNER, L. P., DAMES, S. F. M. and KENDALL, S. B. (1963). 'Chemotherapy of *Babesia*sis'. *Experimental Chemotherapy*, Volume 1, p 621. Editors SCHNITZER, R. J. and HAWKING, F. New York and London: Academic Press

RISTIC, M.(1960). Anaplasmosis.Advances in Veterinary Science, Volume VI. p lrk. Editors BRANDLY, C. A. and JUNGNERR, E. L. New York and London: Academic Press

RYLEY, J. F. (1964). 'A chemoprophylactic approach to *Babesia*sis' . *Res. vet..Sci*. 5,411-418

WILLIAMS, H. E.(1966). *Bovine Anaplasmosis*. Agricultural Research Conference, Jamaica, January. U.W.I. Library, Trinidad (unpubl.)

WOOLFE, G. (1962). 'Antibiotics as antiprotozoal agents in veterinary medicine'. *Antibiotics in Agriculture*, p 70. Editor WOODBINE, M. London: Butterworths

Extracted from Volume 47, Number 2, 1970

Studies in Composite Flours I-The Use of Sweet Potato Flour in Bread and Pastry Making

G. M. SAMMY

Department of Chemical Engineering, University of the West Indies, St Augustine, Trinidad

The use of sweet potato flour as a partial substitute for wheat flour has been studied in India (SINGH et al., 1953), in Israel (PLAUT et al., 1953) and in Peru (FEUNTA, 1960) and it was found that five to ten percent of wheat flour could be so replaced without difficulty. The feasibility of admixing other root-crop flours and defatted oilseed meals with wheat flour for baking has also been studied by ANON, 1953; FINNEY et al., 1950; GREWE, 1945; KIM and DE RUITER, 1968; SUBRAHMANYAN and SWAMINATHAN, 1959; and SUMMERS and THURBER, 1953.

Baked goods made from wheat flour are staple foodstuffs in most parts of the world and especially in the West Indies. Wheat is a typically temperate and sub-tropical plant seldom grown in the tropics, and as most developing countries are in the tropical zone they are therefore dependent on imported wheat for baking. Such countries spend large amounts of their foreign exchange on imported wheat and wheat flour, to reduce which they must find a full or partial substitute for wheat flour.

The Food and Agricultural Organization (FAO) of the United Nations is aware of this problem and is investigating the possibilities of using substitutes derived chiefly from root-crops and defatted oilseeds (FAO, 1968).

In this paper, experiments on the use of sweet potato flour as a partial substitute for wheat flour in baked goods, especially bread, are described and discussed.

MATERIALS AND METHODS

The sweet potatoes used were cvs ‘049’ and ‘C9’, both grown at the University Field Station, St Augustine, Trinidad. ‘049’ is the standard commercial cultivar in Trinidad, while ‘C9’ is an experimental cultivar which has been giving comparatively good yields.

Treatment of tubers

In order to improve the colour of the flour, the tubers were cut into tramverse slices of various thicknesses and treated with different concentrations of sodium metabisulphite for different periods of time in an attempt to improve the colour of the flour by arresting enzyme activity without adversely affecting baking quality.

The best method for obtaining the desired flour was to treat the sweet potato slices, 2 to 3 mm thick, by soaking in a one percent sodium metabisulphite solution for one hour, then washing twice with water before drying or osterizing (preparation of slurry for spray drying).

Preparation of flour

(a) Spray drying—The tubers were cut into slices 2 to 3 mm thick and treated with one percent sodium metabisulphite solution, before osterizing for 15 minutes at medium speed in a Waring Blender (Model CB 5) with twice their weight of water. The slurry obtained was strained through a No 30 sieve and spray dried in batches of about one litre each.

The spray drier used was an A/S Niro Atomizer No 1484 made by Niro Atomizer Ltd, Copenhagen, Denmark, and operated at inlet and outlet temperatures of 200°C and 100°C, atomizer pressure of 4 kg/cm^2 and slurry feed rate of 10 ml/min.

(b) Cabinet drying—The sweet potato tubers were sliced and treated with metabisulphite as for spray drying and then dried in a cabinet drier with an upward draught, at a temperature of 90 to 100°C, to

0041-3216/2021/030248-255

a moisture content of six to eight percent dry weight. The dried slices were ground in a Wiley Mill using a screen with 0.5 mm diameter perforations.

Wheat flour

The wheat flour used was that generally used for bread making in Trinidad. It was milled in Trinidad (Trinidad Flour Mills Ltd) from Dark North spring wheat and contained 12.2 percent crude protein (N% x 6.25), 0.39 percent ash and 13.7 percent moisture.

High protein additives

Cottonseed flour and fish protein concentrate (FPC) were used as high protein additives. Two types of cottonseed flour were obtained from Dr Hugh H. Mottern, Food Products Investigations Engineering and Development Laboratory, U.S.D.A., Agricultural Research Service, New Orleans, Louisiana 70119, U.S.A.: glandless cottonseed flour (No F2051) and Liquid Cyclone Process (LCP) cottonseed flour (No 83169) (awl-Rock et al.,1969).

The fish protein concentrate (FPC) used was manufactured by the VioBin Corporation, Monticello, Illinois, U.S.A. and was obtained from the Trinidad and Tobago Nutrition Unit. Some of the properties of these high protein additives are given in Table 1.

Baking trials

Bread baking trials were conducted under controlled conditions and under home baking conditions using a composite flour containing various proportions of wheat flour, potato flour and high protein adjunct. Table 2 gives the recipes for controlled and home baking.

Controlled bread making procedure

Controlled baking trials were done at the laboratory of the Trinidad Flour Mills Ltd. The dry ingredients (Table 2) and shortening were mixed together. The yeast and sugar were dissolved in water (86 to 104°F) and added to the dry mix with the remainder of the water. The dough was kneaded using a Hobart mixer with a dough hook for two minutes at No 1speed then for five minutes at No 2 speed. The dough was put in a fermentation cabinet kept at 86°F and 75 percent relative humidity for two hours. The dough was scaled and given a further thirty minutes in the fermentation cabinet, after which it was panned and returned to the cabinet where it was allowed to rise again for about 30 to 45 mins. It was then baked at 375°F for 45 mins.

Table 1. Properties of high protein additives

Property	Cottonseed Glandless (F 2051)	Cottonseed LCP (83169)	FPC
Moisture (%)	6·54	—	5·0
Fat (%)	1·42	0·6	—
Protein (N% × 6·25) (%)	57·94	70·0	90·3
Protein solubility in 0·02N NaOH (%)	99·06	98·0	—
Ash (%)	7·33	—	4·9
Crude fibre (%)	2·7	—	Trace
Free gossypol (%)	0·02	≤0·045	—
Total gossypol (%)	0·03	≤0·30	—
Colour	White	Light cream	Light brown
Flavour	Bland	Bland	Bland
Odour	Odourless	Odourless	Very slightly fishy

Table 2. Bread making recipes for controlled and home baking

Constituent	Quantity Controlled Baking (g)	Quantity Home Baking (g)
Composite flour	700·0	350·0
Water	420·0	220·0
Shortening (vegetable)	14·0	5·0
Yeast (compressed)	14·0	—
Yeast (dry granular)	—	2·5
Sugar	28·0	10·0
Salt	7·0	1·5
Powdered skim milk	14·0	10·0

Home bread-making procedure

The dry ingredients (Table 2) and shortening were mixed. The yeast was dissolved in 50 to 75 ml warm water (104 to 120°F) and added to the dry mix with the remainder of the water. The dough was kneaded using a dough hook on a Kenwood Chef at No 3 speed for five minutes. The dough was allowed to prove for one and a half to two hours at room temperature (86 to 90°F). It was then kneaded for three minutes and allowed to prove for a further hour. It was panned, allowed to rise for about an hour to approximately double its bulk and baked at 340 to 360°F for forty to fifty minute:.

Home-baked pastries

The recipes for sponge cake, sweet cream biscuit, pancakes, and doughnuts were taken from HARVEY (1962). The recipe for the sugar cookies was taken from WILSON (1962), while that for raisin bread was taken from ANON, 1963.

Roti (chapati) is an unleavened bread and was made from the following recipe: 2 lb flour, 6 teaspoons baking powder, 1 teaspoon salt and 2 to 2 1/4 cups water. The dry ingredients were mixed together, then kneaded as for bread. The resulting dough was divided into twelve equal portions and formed into balls. This was allowed to stand for one hour, then rolled into circular shapes about nine inches in diameter and about a quarter of an inch thick, and grilled on a hot griddle iron for about five minutes.

Analyses

Colour was determined visually; crude fibre, ash and SO_2 by A.O.A.C. method (A.O.A.C., 1965); moisture by direct oven method at 105°C and by moisture balance (CENCO). Total nitrogen, determined by micro-Kjeldahl method, was used for calculation of the crude protein content (N%x 6.25). Reducing and total sugars were determined by the volumetric method of Lane and Eynon (PEARSON,1962) and total fat by Soxhlet extraction using carbon tetrachloride as solvent Bread volume was determined by displacement using rapeseed.

RESULTS AND DISCUSSION

Table 3 gives some properties of the fresh tubers of sweet potato cultivars '049' and 'C9'.

Table 3 some properties of the fresh tubers of sweet potato cvs '049' and 'C9'.

Property	Cultivar '049'	Cultivar 'C9'
Shape	Globular	Cylindrical
Skin colour	Light reddish brown	White
Flesh colour	White	White
Moisture (%)	69 to 71	66 to 69
Starch (by diff.) (% dry wt)	83·64	82·92
Crude protein (% dry wt)	3·50	3·06
Fat (% dry wt)	0·48	0·62
Reducing sugars (% dry wt)	3·24	3·24
Total sugars (% dry wt)	6·31	7·12
Fibre % dry wt)	1·18	1·62
Ash (% dry wt)	1·65	1·62

Effect of peeling tubers on flour properties and baking characteristics

Table 4 gives some properties of flours obtained from untreated slices of peeled and unpeeled sweet potato. Peeling had little effect on these properties. Baking trials using a white wheat flour to which had been added ten and fifteen percent of these flours gave products that were indistinguishable in colour, texture and taste. Flour from unpeeled sweet potatoes was therefore used in all subsequent experiments.

Effect of SO_2 treatment on colour and baking properties

Improvement in colour of the raw flour was obtained without loss of baking quality by SAKURAI et al. (1953) in flour containing more than 120 ppm SO_2.

Table 4. Some properties of spray-dried light brown flour prepared from untreated slices of the peeled and unpeeled sweet potato cultivars

	Cultivar '049'		Cultivar 'C9'	
	Peeled	Unpeeled	Peeled	Unpeeled
Moisture % (dry wt)	3·24	3·34	3·12	3·15
Fibre % (dry wt)	0·92	1·20	1·57	1·69
Ash % (dry wt)	1·58	1·72	1·69	1·74
Reducing sugars % (dry wt)	4·05	4·31	3·15	3·00
Total sugars % (dry wt)	8·24	8·04	7·22	7·12
Crude protein % (dry wt)	3·8	3·6	3·0	2·8
Particle size:				
Through No. 150 Sieve (%)	69·4	69·0	68·8	68·4
Through No. 100 retained on No. 150 Sieve (%)	14·5	14·3	20·5	21·0
Through No. 60 retained on No. 100 Sieve (%)	16·1	16·7	10·7	10·6

However, our baking trials have indicated adverse effects on baking properties when the SO_2 content exceeded 100 ppm.

Soaking sweet potato slices of 2 to 3 mm thickness in a one percent sodium metabisulphite solution for one hour, and washing twice with water before drying, gave a cream coloured flour with an SO_2 content of 25 to 50 ppm and with unimpaired baking properties.

Effect of sweet potato flour particle size on loaf volume

The sweet potato flour was graded into three batches, the first containing all flour passing through a No 200 sieve, the second containing those in the range No 100 to No 200 sieve and the third containing those in the range No 60 to No 100 sieve. The total sweet potato flour was made up of 54 percent of batch one, 39 percent of batch two and 7 percent of batch three.

Batches of composite flour were made up containing 15 percent of any one grade and made into bread to test the effect of sweet potato flour particle size on loaf volume. Table 5 shows that as the particle size decreased the loaf became denser, giving a smaller volume of bread. The small decrease in volume of loaf with particle size may be due to the larger amount of free starch in the batch with particle sizes all passing through a No 200 sieve.

Effect of introducing various quantities of potato flour

(a) ‘049’ Flour

Introduction of 15 percent ‘049’ flour gave a loaf which was almost identical to the standard wheat loaf, except for the light grey colour of the crumb. A twenty percent introduction gave a smaller and less attractive loaf. It had a very slight off-odour and taste when hot, but this disappeared on cooling. This loaf was acceptable but less so than the 15 percent loaf. The 25 percent loaf was unacceptable because of its distinct off-flavour and taste. The loaves are illustrated in Figure I.

An acceptability trial with ten families (40 individuals) showed full acceptance for the 15 percent loaf. The crumb colour was commented upon but no objection was raised.

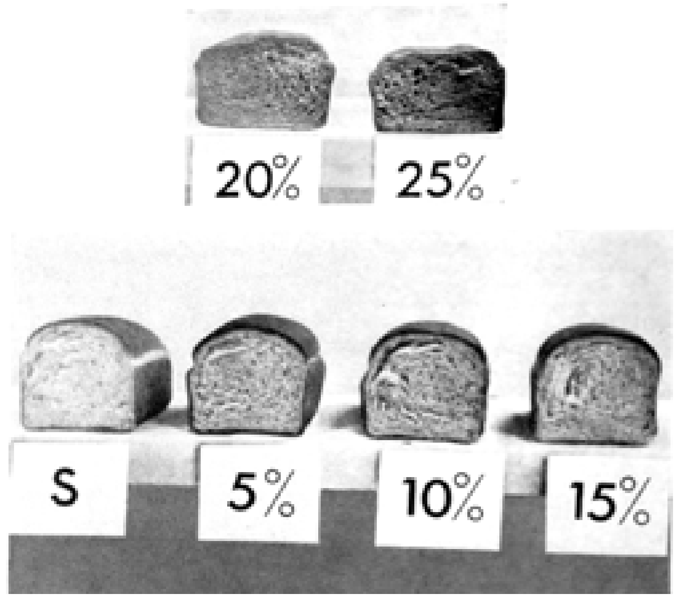


Figure 1. Loaves containing various proportions of sweet potato flour. S denotes the standard loaf (100 percent wheat). Percentages denote proportion of sweet potato flour in each loaf

(b) ‘C9’ Flour

Bread containing five percent ‘C9’ flour gave an acceptable loaf; with ten percent the loaf was fair, but that from 15 percent substitution was unacceptable.

Table 6 gives the properties of bread baked from composite flours containing varying proportions of sweet potato flour.

Comparison of spray-dried and cabinet-dried flours

Table 7 gives some properties of spray-dried and cabinet-dried flours prepared from treated slices of ‘049’. The products were similar except for the higher moisture content of the cabinet-dried flour and the higher sugar content of the spray-dried flour. The latter possibly arose from hydrolysis of the slurry during preparation and storage in the feed hopper while spray drying. Bread baked from 15 percent substitution gave very similar products. Table 8 gives the properties of the bread.

Table 5. Relationship between sweet potato flour particle size and loaf volume

Particle size batches	*> No. 200 Sieve*	*No. 100 to No. 200 Sieve*	*No. 60 to No. 100 Sieve*	*Total*
Loaf volume ml/g	3·3	3·4	3·5	3·5
ml/kg flour	5800	5950	6200	6205

Table 6. Effect of different proportions of sweet potato and wheat flour on characteristics of loaves baked under controlled conditions

Character	Cultivar								
	'049'						'C9'		
Sweet potato flour %	0	5	10	15	20	25	5	10	15
Loaf volume:									
ml/g	4·6	4·2	4·3	4·3	3·7	2·8	4·0	3·8	2·7
ml/kg flour	7429	7214	7286	7357	6333	5000	7000	6428	4571
Shape:	stable	stable	stable	stable	slight fall	fallen	stable	slight fall	fallen
Colour:									
crust	pale brown	pale brown	brown	brown	brown	brown	pale brown	brown	brown
crumb	white	light grey	light grey	light grey	light grey	light grey	light grey	light grey	light grey
Texture:									
crust	smooth	smooth	smooth	smooth	rough few cracks	rough many cracks	smooth	rough few cracks	rough many cracks
crumb	cells even (good)	cells even (good)	cells even (good)	cells even (good)	cells uneven (very fair)	cells uneven (fair)	cells even (good)	cells uneven (very fair)	cells uneven (fair)
Taste:	good	good	good	good	fair	poor	good	fair	poor

Table 7. Some properties of spray-dried and cabinet-dried flours prepared from slices of sweet potato cv. '049'

Method of Drying		Spray	Cabinet
Colour		cream	cream
Moisture % (dry wt)		2·48	7·2
Fibre % (dry wt)		1·20.	1·42
Ash % (dry wt)		1·71	1·55
Reducing sugars (dry wt)		4·43	2·80
Total sugars % (dry wt)		8·24	6·30
Crude protein % (dry wt)		3·5	3·2
Fat % (dry wt)		0·40	0·41
Particle size:			
Through No. 150 Sieve	%	69·2	68·0
Through No. 100 retained on No. 150 Sieve	%	14·8	20·5
Through No. 60 retained on No. 100 Sieve	%	16·0	12·5

Comparison of controlled and home baking

In most developing countries baking is commonly done by primitive manual methods and seldom with semi-automatic equipment. A comparison was therefore made between baking under conditions which were all carefully controlled and baking under home conditions where personal judgement was used.

Except for a difference in loaf volume between the controlled and the home baked bread, the loaves were identical. Table 9 gives the loaf volumes for controlled and home-baked bread.

Use of binding agents

It has been reported (Jongh et al., 1968 and KIM and De Ruiter, 1968) that the problem with root-crop flour doughs arises from the absence of the strongly cohesive and elastic properties of wheat flour doughs. Jongh showed that the addition of one percent glyceryl monostearate strengthens the root crop flour dough and produces a loaf of greater volume and better crumb texture. This was confirmed by KIM and DE Ruiter who studied 20 different binding substances using a composite flour made up of 70 percent yam flour and 30 percent low fat groundnut flour.

In an attempt to increase the proportion of sweet potato flour, one percent glyceryl monostearate and one percent glyceryl monopalmitate (commercial grades) were added to two composite flours, one containing 20 percent '049' and 80 percent wheat flour and the other 20 percent '049', five percent of a high protein additive and 75 percent wheat flour. Three high protein

Table 8. Characteristics of bread baked under home conditions from a mixture of 85% wheat flour and 15% spray-dried or cabinet-dried sweet potato flour made from treated slices of cv. '049'

	Flour type	
	Spray dried	*Cabinet dried*
Loaf volume		
ml/g	3·5	3·5
ml/kg flour	6200	6205
Shape	*Normal*	*Normal*
Colour		
Crust	*Brown*	*Brown*
Crumb	*Light grey*	*Light grey*
Texture		
Crust	*Smooth*	*Smooth*
Crumb	*Cells even, normal*	*Cells even, normal*
Taste	*Good*	*Good*

Table 9. Comparison of loaf volume between controlled and home-baked bread

Method of baking	*Controlled*		*Home*	
Composite flour	100% Wheat	15% '049'	100% Wheat	15% '049'
Volume:				
ml/g	4·6	4·3	3·7	3·5
ml/kg flour	7429	7357	6500	6200

additives were used, fish protein concentrate and two types' of cottonseed flour.

The results obtained as shown in Table 10 were disappointing because the small improvement in loaf volume, shape and texture was smaller than had been expected from previous reports.

Effect of high protein additives on baking properties

Table 11 shows that the addition of five percent of a high protein concentrate such as fish protein concentrate or cottonseed flour to a composite flour containing 20 percent potato flour had very little effect on the baking properties. The texture and flavour did not differ from that of bread made from composite flour containing 75 percent wheat flour.

Effect of sweet potato flour on pastries

Composite flours containing various proportions of sweet potato flour were used for making pastries (Table 12). The proportion of sweet potato flour that could be used increased in accordance with the sweetness of the product, ranging from 15 percent for unleavened bread to 30 percent for cookies.

Quality of the product was related to the sweet potato cultivar from which the flour was made, and at any given rate of admixture with wheat flour '049' gave a more acceptable product than 'C9', although neither yielded a satisfactory biscuit. The data in Table 3 give no indication of why '049' should have better baking properties than 'C9'. The differences in fibre, sugar, fat, and crude protein content seem too small to affect the baking properties to so great an extent.

Table 10. Effect of glyceryl mono-esters on bread made from a mixture of 80% wheat and 20% sweet potato ('049') flour under home baking conditions

	Composite flour	*Composite flour plus 1% glyceryl monostearate*	*Composite flour plus 1% glyceryl monopalmitate*
Loaf Volume:			
ml/g	2·9	2·9	3·1
ml/kg flour	5050	5100	5400
Shape:	*Slight fall*	*normal*	*normal*
Colour:			
crust	*Light brown*	*light brown*	*light brown*
crumb	*light grey*	*light grey*	*light grey*
Texture:			
crust	*Rough, few cracks*	*smooth*	*smooth*
crumb	*uneven cells*	*uneven cells*	*uneven cells*
Taste:	*slight potato*	*slight potato*	*slight potato*

Table 11. Effect off five per cent high protein additive and binding agents on bread made from a mixture of 75% wheat and 20% sweet potato flour (cv. '049') under home baking conditions

	High protein additive								
	FPC Binding agent			Cottonseed flour (glandless) Binding agent			Cottonseed flour Binding agent		
	0	1% stearate	1% palmitate	0	1% stearate	1% palmitate	0	1% stearate	1% palmitate
Volume:									
ml/g	2·9	2·9	2·8	2·6	2·8	2·8	2·7	2·8	2·8
ml/Kg	5100	5050	5000	4600	4750	4700	4800	4850	4900
Shape:	normal	normal	normal	normal	normal	normal	normal	normal	normal
Colour:									
crust	pale brown	pale brown	pale brown	brown	brown	brown	golden brown	golden brown	golden brown
crumb	grey	grey	grey	light grey	light grey	light grey	yellowish	yellowish	yellowish
Texture:	uneven, cells larger at top, compressed at bottom, gritty to the tongue			uneven, cells larger at top, compressed at bottom			uneven, cells larger at top, compressed at bottom		
Taste:	All had slight off flavour			All had slight off flavour			All had slight off flavour		

Table 12. Effect of sweet potato flour on pastry quality

Product	% Sweet Potato flour	Cultivar '049'	Cultivar 'C9'
Roti (unleavened bread)	15	good	poor
Sponge cake	20	good	poor
Raisin bread	20	good	poor
Cookies	30	good	poor
Pancakes	20	good	poor
Doughnuts	20	good	poor
Sweet cream biscuits	15	poor	poor

Good denotes acceptable as compared with product made from all wheat flour.
Poor denotes unacceptable.

Sweet potato flour prepared from cultivar '049' may be used without any difficulty as a substitute for wheat flour at a rate of up to 15 percent in bread making and at 20 to 30 percent in pastries. Bread containing 20 percent was also acceptable although less so than that containing 15 percent. Flour from this cultivar was of poor quality for bread and pastries.

Flour made from peeled and unpeeled sweet potatoes differed little in baking properties. Sodium metabisulphite treatment improved the colour of the flour, but an SO2 content greater than 100 ppm affected baking properties.

Addition of one percent glyceryl monostearate and one percent glyceryl monopalmitate to the composite flour only slightly improved the bakingproperties.

A high protein additive had little effect on baking properties.

ACKNOWLEDGMENTS

This work was part of the Root-crop Programme of the Faculty of Agriculture, University of the West Indies and was sponsored by the Rockefeller Foundation.

The author is grateful to Mr G. Reid of the Trinidad Flour Mills Ltd who did the controlled baking and to Mrs Myrtle Sammy, his wife, who did all the home baking.

(Received November 1969)

REFERENCES

ANON.(1953).'Physiological aspects of breadmaking with cassava'. *Bull. Inst. Fusiol. (Asuncion Paraguay)* No. 18

ANON. (1963). *Better Homes & Gardens, Bread Cook Book*. Des Moines, U.S.A.: Meredith Press

A.O.A.C. (1965). Official Methods of Analysis, 10th Ed., Washington, D.C.

F.A.O./Industry Cooperative Programme (1968). 'Note on mechanically developed doughs from composite flours'. IP/Ag S: G/68/20

FEUNTA., R. LUNA de la (1960). 'Experiments in breadmaking from flour mixtures of wheat and three varieties of sweet-potato' . *Peru Bol. Trimester Exp. Agropec.* 9 (3), 10-16

FINNEY, K. F., BODE, C. E., YAMAZAKI, W. T., SWICKARD, M. T. and ANDERSON, R. B. (1950). Baking properties and palatability studies of soy flours in blends with hard winter wheat flour '. *Cereal Chem*. 27,312-322

GASTROCK, A. D., AQUIN, E. L., EAVES, P. H. and CROSS, D. E. (1969). 'Edible flour from cottonseed by liquid classification using hexane'. C*ereal Sci. Today,* 14 (1)

GREWE, E. (1945). 'Use of peanut flour in baking'. *Food Res.* 10, 28-31

HARVEY, P. (1962). *A Guide to Good Cooking*, 20th Ed. Montreal: Lake of the Woods Milling Company Ltd

JONGH, G., SLIM, T. and GREVE, H. (1968). 'Bread without Gluten'. *Bakers Digest*, 42 (3),24-29

KIM, J. C. and DE RUITER, D.(190). Bread from non-wheat flours '. *Food Tech*., 221/867-878

PEARSON D.. (1962). *Chemical Analysis of Foods*. London: Churchill

PLAUT, M. and ZELZBUCK, B. (1958). 'Use of sweet-potato for flour and bread'. *Ktavim* 8, 77-92

SAKURAI, Y., WATANABE, T. and YOKOZAWA, I. (1953). 'Dehydration of sweet-potatoes by compression after treatment with chemicals'. *Rep. Fd Res. Inst.* (Japan) 2,63-65

SINGH, R., RAPIGUE, M. and BAINS, G. S. (1953). 'Investigations on the preparation and use of sweet-potato and groundnut cake flours in conjunction with what for leavened bread'. *J. Agric. Sci.*, 23 (11), 139-146

SUBRAHMANYAN, V. and SWAMINATHAN, M. (1959). 'Utilization of tuber crops for meeting food shortage'. *Food Sci.* (India), May 1959,177-182

SUMMERS, J. C. and THURBER, F. H. (1953). 'Protein enrichment of baked goods by addition of cottonseed flour'. Paper presented at 28th Ann. Meeting, Amer. Assoc. Cereal Chemists

WILSON, L. (1962). *Fancy Cookies, Donuts and Pastries*. Wisconsin: Mirro Aluminium Co.

Extracted from Volume 56, Number 4, 1979

The impact of plant breeding on sugar-cane in Barbados

N. W. SIMMONDS

Edinburgh School of Agriculture, West Mains Road,
Edinburgh EH9 31G, Scotland

The historical and agricultural background of Barbados sugar-cane agriculture is outlined. Since the late nineteen thirties, four cycles of varieties have been grown. Regression analysis of cane yields (based upon extensive commercial data) permits the separation of varietal effects on yield from an underlying curved trend due to changing weather and husbandry. The three sets of newer varieties varied in the yield advantage achieved over their predecessors and there were evident genotype-environment (GE) effects. Collectively, the grain was large and the new canes added about 6.7 Mt to total crop over a 36 year period; they also ratooned better, a further contribution to economy of production. There is no evidence of change in sugar content. In discussion, the biological and economic consequences of cane breeding, the importance of GE effects, implications for the interpretation of trials results and the need to widen the genetic base are topics touched upon.

INTRODUCTION

There is a widespread belief, among farmers, agricultural scientists and administrators alike, that plant breeding has been highly successful in promoting agricultural productivity either by enhancing yields per unit cost or by better matching the quality of the product to the needs of the consumer. This belief, however, has very rarely been tested by reference to actual agricultural data; it rests, rather, upon the expectation that results of trials truly reflect the agricultural reality. This belief, too, is untested and there exists at least one body of opinion to the effect that trials in agricultural research in general are but poor predictors (DAVIDSON, 1965; DAVIDSON and MARTIN, 1965). The principal obstacle to testing the effects of plant breeding in practice is, perhaps surprisingly, simply lack of usable data: very few crop yields are adequately recorded. Sugar-cane, however, provides an exception and a fine series of yield data from that crop in Barbados provides the subject matter of this paper.

BACKGROUND

Sugar-cane is a large perennial, stooling grass. It is clonally propagated by planting pieces of stem. At harvest, leaves and sheaths (`trash') are left behind and the stems are removed to the factory and crushed; the expelled juice yields sucrose and the fibrous remains (`bagasse') are used to fuel the factory. The first crop (`plant' crop, P) is taken in 12 to 15 months from planting and subsequent crops ('ratoons', R_1, R_2, R_3, etc) at yearly intervals. Ratoon yields decline at various rates in various places and replanting is ultimately necessary. The cause of decline in unknown, but the fact that it occurs and its rate are of great economic importance. Harvest is always in a dry (and preferably also cool) season; this checks growth, enhances sugar content of the juice, facilitates movement in the field and minimizes damage to soil structure.

The foregoing is a quite general summary of sugar-cane agriculture. Local practice varies very widely indeed, as might be expected of a crop that is widely adapted throughout the tropics and subtropics and is variously produced by industrial-style estates, farmers and peasants. Indeed, no two cane agricultures are quite alike, even within a small and relatively homogeneous area such as the West Indies. Barbados has several distinctive features. The early history was summarized by SAINT (1954) and STEVENSON (1960), later events by HUDSON (1973) and B.S.P.A. (1973) ; see also Sum (1976). Early history need not concern us here, beyond noting that the island has a continuous record of sugar production from 1640; for the present

0041-3216/2021/030256-264

purpose, the interesting period is the last 37 years.

Barbados is a small Atlantic island (430 km^2, 13°N). Soils are sedimentary in origin and variable in character. Topography is undulating and generally low (maximum altitude 340 m). Rainfall is erratic, mostly in the range 1000 to 2000 mm/year and mostly falling in the period June to December; cane is harvested in the dry season February to May. Long-term rainfall cycles have long been suspected and recently established to occur on a 55 year cycle or thereabouts (BARR, personal communication, 1978; and see below). Within the island there is considerable variation and three rainfall areas are conventionally distinguished: low (L) (1000 mm, low-lying, coastal); medium (M) (1500 mm); high (H) (2000 mm, higher and generally more easterly-exposed topography). All students agree that rain is the major limiting factor for growth; HUDSON (1973) has developed an empirical `effective rainfall' equation which accounts rather well for seasonal variation in yield. The area cultivated in estate cane in the past 35 years has been in the range 10 to 14 kha distributed on average thus: L, 16 percent; M, 44 percent; H, 40 percent. The L area has fallen in the last decade in response to droughts and alienation of coastal land for other purposes. Estates are small, averaging 80 ha and are commonly family-owned; they would perhaps better be described as farms. There is also a substantial peasant cane production. The data used in this paper are based solely on the estates which render regular returns, accounting on average for about 70 percent of the cane area. Numerous small estates were, historically, matched by numerous small factories, but their number has shrunk in recent years to nine, making a total of about 120 kt of sugar (peak, mid-nineteen sixties, about 180 kt).

At its peak, in the nineteen fifties and early sixties, Barbados cane agriculture was outstandingly efficient, regularly producing 10 t/ha of sugar and, in many years, 11.3 t/ha. Indeed, it had something of the character of a horticulture. Cane was planted on the cane-hole pattern which is conservative of moisture; fertilizing was good; weeds were controlled by hoe; little heavy equipment was used; harvest was by hand and all trash was returned as mulch, to the joint benefit of soil and water conservation. The rising yields of the late nineteen forties (Figure 2) were mainly due to improved mineral fertilizing in addition to the traditional pen manure and mulch. The decline since the mid-nineteen sixties is related to recurrent droughts, labour shortage, probably to herbicide damage (WALKER, personal communication, 1978) and, above all, to burning. The last practice (now illegal) certainly made harvest easier and cheaper but destroyed potential mulch, damaged the soil, reduced ratoon yields, reduced sugar content (causing 'stale cane') and hampered sugar recovery in the factory.

The crop is generally planted about October and plants are reaped about 15 months later. Ratoons are thereafter taken at intervals of 12 months until declining yields enforce replanting. Survival is better the higher the rainfall and, as will appear below, has increased over the years. The planters' decision system for replanting is not known but must involve some sort of economic calculation, balancing declining returns against replanting costs (SIMMONDS, 1973).

It is against this complex background of changing husbandry and fluctuating environment that the effects of varietal change in Barbados must be viewed. The early history of varieties in Barbados has been reviewed by STEVENSON (1952, 1960, 1965) and need not concern us here but one might recall that Barbados was, with Java, one of the two pioneers in cane breeding. General breeding history of the crop has been summarized by SIMMONDS (1975). At the beginning of the period in question, the Barbados cultivation was dominated by three noble canes (N) (Table 1) and had been dominated by their parents and predecessors for the previous 140 years. Noble breeding produced successful new varieties from about 1900 onwards but there are no data by which their effects might be assessed.

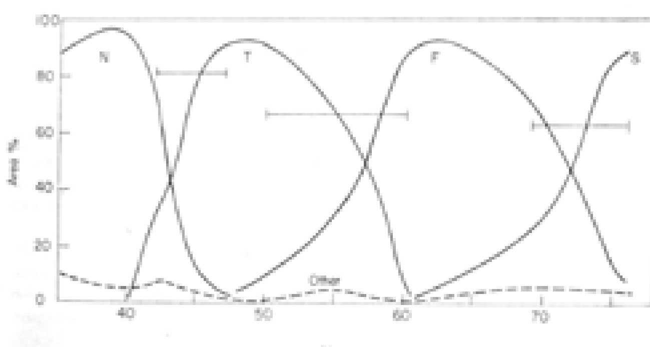


Figure 1. Four cycles of sugar-cane breeding in Barbados. Noble canes (N), Thirties (T), Forties (F) and Sixties (S). See Table 1 and text. The three horizontal lines show the periods over which contemporary yield comparisons were made (Table 2). The broken line represents the small residue of unidentified and minor varieties.

Table 1. History of leading sugar-cane varieties in Barbados*

Period	*Features*
Before 1942	Noble canes (*N*) dominant. *N1*: BH10/12; 1919–49; 30% in 1938; *H* *N2*: B726; 1930–47; 30% in 1938; *M* *N3*: B2935; 1933–45; 46% in 1941; *L* and *M*
1940–48	Transition, Noble (*N*) to Thirties (*T*). Sequence *M–L–H*; yield comparisons 1942–47
1945–55	Thirties (*T*) canes dominant. *T1*: 37161: 1942–63; peak 93% in 1949; *L*, *M* and *H*
1948–62	Transition, Thirties (*T*) to Forties (*F*). Sequence *H–M–L*; yield comparisons 1950–62
1958–69	Forties canes (*F*) dominant. *F1*: B41211; 1950–73; peak 26% in 1960; *L* and *M* *F2*: B45151; 1955–72; peak 22% in 1962; *M* and *H* *F3*: B4744; 1954–78; peak 33% in 1970–71; *M* and *H* *F4*: B49119; 1958–74; peak 30% in 1963–66; *L* and *M*
1962–76	Transition, Forties (*F*) to Sixties (*S*). Sequence *M–L–H*; yield comparisons 1969–76.
1974 onwards	Sixties canes (*S*) dominant. *S1*: B59162; 1971– ; peak 19% in 1975; *L* and *M* *S2*: B60267; 1970– ; peak 12% in 1974; *M* and *H* *S3*: B62163; 1972– ; peak 53% in 1976; *L*, *M* and *H*

* See also Figure 1

Table 2. Three cycles of sugar-cane varietal change in Barbados. Survival, yield and yield regressions during the transitional periods

		Rainfall area									
		Low		*Medium*		*High*		*Regression*			
		X	*Y*	*X*	*Y*	*X*	*Y*	*N*	*r*	*a*	*b*
(1) *N* and *T*											
Survival	(year)	1·4	1·7	1·8	2·2	2·0	2·7	—	—	—	—
Yield (t/ha)	*P*	**65·5**	**72·8**	**75·1**	**87·6**	**87·6**	**91·4**	15	0·871	17·1	0·873
	R_1	49·7	56·7	55·0	69·5	72·1	**76·1**	13	0·768	22·1	0·754
	R_2	—	—	—	—	65·0	65·5	8	0·474	50·2	0·221
(2) *T* and *F*											
Survival	(year)	2·5	3·1	2·9	3·4	3·6	3·6	—	—	—	—
Yield (t/ha)	*P*	**80·6**	**91·1**	**93·9**	**102·4**	**105·2**	**114·5**	31	0·952	2·0	1·082
	R_1	67·3	**78·3**	**75·8**	**87·9**	**90·4**	**104·2**	31	0·963	6·3	1·077
	R_2	62·8	70·8	72·8	83·9	**80·1**	**99·2**	30	0·938	−4·8	1·239
	R_3	62·3	69·8	67·8	76·6	67·5	84·6	24	0·887	4·0	1·114
(3) *F* and *S*											
Survival	(year)	3·3	3·7	4·0	4·2	4·3	5·0	—	—	—	—
Yield (t/ha)	*P*	**55·5**	**66·5**	**75·6**	**80·8**	**94·7**	**88·6**	16	0·853	40·7	0·517
	R_1	**39·2**	**44·2**	**62·0**	**68·0**	**90·6**	**85·4**	15	0·967	14·3	0·823
	R_2	39·4	47·0	51·7	**59·5**	**78·1**	**76·3**	15	0·919	21·8	0·688
	R_3	—	—	47·5	54·2	69·8	**66·3**	10	0·897	29·9	0·530
	$R_{4,5}$	40·4	44·2	50·7	53·0	64·8	63·5	—	—	—	—

Notes:

1. For each cycle, T, the independent variate in the regression columns, is the new variety or varieties that displaced the old, thus: (1) *T* on *N*; (2) F on *T*; (3) *S* on *F*.
2. In the columns headed Regression, N is the number of data-pairs in each entry, r the correlation coefficient, a the intercept and b the regression coefficient
3. Mean yields unbiased by ratoon selection (>90 percent survival) shown in **bold face**

It was the last of these nobles that were displaced by the new interspecific hybrid-derived canes in the period now being reviewed. Three clear cycles of replacement may be distinguished (Figure 1, Table 1). The first cycle, the canes bred in the nineteen thirties (T), was effectively represented in Barbados by one clone, B37161; other representatives of these early `nobilizations' were successful elsewhere in the West Indies (e.g. B34104) but not in Barbados. The second and third cycles [Forties (F) and Sixties (S) in Table 1] were, broadly speaking, the products of two rounds of generationwise assortative mating of the T canes.

These cycles were represented in Barbados by three or four varieties each (Table 1); again, different clones succeeded elsewhere in the West Indies (McCoLL, 1971). All the varieties included in the present study attained at least ten percent of the Barbados area and persisted for a decade; collectively they account for over 90 percent of the total area reported upon (Figure 1).

The data upon which this paper is based were all published in a series of annual reports that started in 1936 under the general title 'The yields of sugar cane in Barbados' (VARIOUS AUTHORS, 1936-76) ; earlier issues were printed for the Department of Agriculture Barbados, later ones mimeographed. These reports summarize cane yields by variety, crop and locality and are based on estate returns. Factory returns are also recorded and published but on an island basis and cannot, unfortunately, be related to variety. We therefore have very good information on cane yields by variety but none on sugar content.

Abbreviations adopted in this paper have been given above and may conveniently be summarized as follows:

Crops:	P (plant), R_1, R_2, R_3 etc (ratoons)
Areas, rainfall:	L (low), M (medium), H (high)
Varietal cycles:	N (Noble), T (Thirties), F (Forties), S (Sixties).

RESULTS

Cane yields and longevity

The results to be described mostly relate to cane yield and attention will be given first to the periods in which varietal comparisons can be made unconfounded by seasonal effects, namely the three transitional periods detailed in Table 1. As this table and Figure 1 show, the first transition was remarkably rapid, the second much slower and the third intermediate in rate. All three resulted in about 90 percent of the area (after the transition had been effected) being occupied by the leading varieties specified in Table 1. Survival and yields are summarized in Table 2. Survival is defined as the mean age at replacement and it was estimated by constructing, in effect, life tables. Yield comparisons were based on pairs of values, for new and old varieties, in the same rainfall area, in the same year and in the same stage of the crop cycle. Except that very small areas were discarded, all the data were used, so the results are founded on enumeration of a substantial part of the island's crops in those years.

Conclusions are that: (1) all three cycles of replacement resulted in longer ratooning in all areas (but see also below) and that this was superimposed on the expected differences between areas (H> M> L) and upon an underlying upward trend of survival with time; (2) the first two cycles also resulted in substantial increases in cane yield, superimposed, like survival, on expected differences between rainfall areas and an upward trend with time; (3) the third cycle took place against a background of recurrent drought and declining husbandry (see above); the new varieties (the Sixties canes) showed a clear yield advantage only in the harder conditions and were actually lower-yielding than the Forties in the better areas.

The regressions in the last two columns of Table 2 are based on all available data across rainfall areas, since these were found to be (with one exception) homogeneous. Regressions between crops, especially in the later ratoons, were probably somewhat heterogeneous; since many ratoon crops had been fairly severely selected in preceding years, complete homogeneity would perhaps be surprising but no evident pattern emerges. For the first cycle, despite ratoon selection, P and R were homogeneous. For the second and third cycles first ratoon survival was high, P and R1 were homogeneous and the joint regressions were (t/ha) :

$$\mathcal{Y}_T = 16.5 + 0.864\ \mathcal{Y}_N \qquad (r=0.865,\ \mathcal{N}=28) \quad (1)$$

$$\mathcal{Y}_F = 8\text{-}8 + 1.024\ \mathcal{Y}_T \qquad (r=0.959,\ \mathcal{N}=62) \quad (2)$$

$$\mathcal{Y}_S = 24.9 + 0.696\ \mathcal{Y}_F \qquad (r=0.912,\ \mathcal{N}=31) \quad (3)$$

Correlations are generally high, sometimes very high. There was no evidence of non-linearity. The regression coefficients just given are, as `functional relationships', somewhat underestimated because of 'attenuation' due to `departures' in the independent variate (SPRENT, 1969). Several alternative estimates are available (see RICKER, 1973, for general discussion) of which the one used here is that which minimizes sums of squares of deviations perpendicular to the line. So adjusted, the equations become:

$Y_T = 9.8 + 0.999\, Y_N$ (4)

$Y_F = 6.4 + 1.071\, Y_T$ (5)

$Y_S = 22.4 + 0.744\, Y_F$ (6)

These equations imply widely varying differences in adaptability. T (with b =1) was constantly superior to N by about 10 t/ha at all levels of performance; F (with b > 1) was slightly more responsive than T to good conditions but superior everywhere; S (with b < 1) is superior to F only under poor conditions (as is also evident from mean yields over areas in Table 2).

In Figure 2, yields in the three rainfall areas were combined as means, weighted by areas, to give estimates of island plant crop yields had N, T, F and S been grown alone for the whole period. The unbroken parts of the lines represent actual yield data; the broken parts were constructed from the regressions given above.

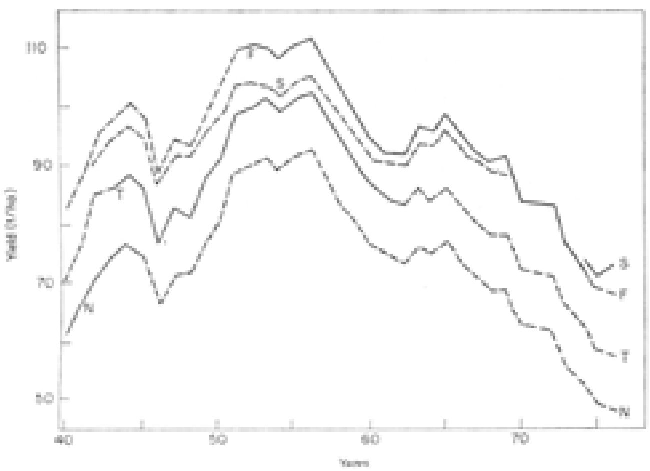


Figure 2. Plant crop cane yields in Barbados by the four groups of varieties. Means, weighted by areas over the three rainfall zones, plotted as five year moving averages. Unbroken lines are actual yields, as observed, broken lines are calculated from regressions (see text)

Trial calculations show that the exact form of regression chosen is not very critical and would not affect the main conclusions that: the two earlier cycles were roughly equal in effect and jointly added about 20 t/ha to plant crop yields; and the superiority of the S clones to F in the drier parts is so closely compensated by lower yields elsewhere (Table 2) that mean performance has differed but little.

There is no doubt therefore that the new canes contributed greatly to yield in the plant crop. What, then, of survival and yield in the ratoons? Table 2 shows, remarkably consistently over rainfall areas, that each cycle was accompanied by prolonged survival; on an all-island basis the average life of a field increased from 1.8 to 4.5 year over the 35 year period and it looks as though about 1.2 year of this 2.7 year increase could have been due to the new varieties. This is an upper estimate because any underlying trend is confounded with varietal change during the transition period. The local tradition, however, is strong that the newer varieties have ratooned better than the old ones but the effect does not seem to be as big as might have been expected; certainly there has been an underlying upward trend of longevity, the product of economic pressures and independent of variety.

Data on ratoon yields unbiased by selection are sparse. Table 2 shows that, virtually everywhere, the decline from P to R is greater than from R_1 to R_2. This, as noted above, is expected, because of the longer

Table 3. Yields (t/ha) of plant and ratoon crops, orthogonal with respect to season and unbiased by ratoon selection

Cycle	No. of observations	Crop P	Crop R_1	Crop R_2	Difference $P-R_1$	Difference R_1-R_2
N	5	87·7	72·6	—	15·1	—
T		91·3	76·2	—	15·1	—
Difference					0·0	
T	8	106·0	90·8	80·5	15·2	10·3
F		116·9	106·3	98·8	10·6	7·5
Difference					4·59†	2·81‡
F	12	84·1	75·3	67·2	8·9	8·0
S		83·8	75·1	71·8	8·7	3·3
Difference					0·20	4·67§

Tests of differences were all positive but none significant:
† t [7 *d.f.*] = 4·59/2·10 = 2·18
‡ t [11 *d.f.*] = 2·81/1·48 = 1·91
§ t [11 *d.f.*] = 4·67/2·76 = 1·70

growth of the plant crop. The data of Table 2, however, are non-orthogonal with respect to seasons; extraction of orthogonal data yielded Table 3.

Regressions of P on R_1 and R_1 on R_2 showed that B1, so constant decline at all yield levels is indicated. Table 3 suggests that ratoon yields have been better sustained in recent years and that the two latest cycles of new varieties were superior to their predecessors in this respect. None of the relevant t, however, is significant though all are suggestive. On balance it looks as though the advantage might be 2 to 5 t/ha in two successive crops but the amount is not well estimated and it is clear that any gain in this respect is smaller than the plant crop effect (Figure 2) sustained over crops. In summary, therefore, it seems certain that new varieties survived longer than their predecessors and at least likely that their ratoon yields declined a little more slowly.

Sugar content

The results so far have all referred to cane yields and longevity. Turning now to sugar content (Q, sucrose percent cane), there are, as noted above, no data by varieties and any analysis must depend on examination of trends of Q with time. In the event, no clear conclusions are possible (Table 4); any apparent regression of means of Q, on time is non-significant. Reporting in the early years was incomplete; there was a rising trend of factory efficiency in the nineteen forties; there is some negative relationship between cane yield and Q because rainfall that favours one disfavours the other; and the potentially favourable effect of recent droughts on Q have been substantially offset by the deleterious effects of burning. Any possible varietal effects are hopelessly confounded with these other changes. Local tradition is strong that new varieties have been at least no worse than their predecessors but, while no doubt true, this belief is strictly untestable. Trials in Guyana of materials comparable with the N—T—F cycles treated here suggested considerable improvement in Q (Simmonds, 1976) but the result obviously cannot be extrapolated to different varieties at a different time in a different place.

Table 4. Out-turn of sugar (Q) from Barbados factories for various periods characterized by varieties grown, 1936-76. Q as 96° sucrose percent off fresh cane

	Period					
	1936–42 N	*1943–46* N–T	*1947–51* T	*1952–61* T–F	*1962–69* F	*1970–76* F–S
No. of years	7	4	5	9†	8	7
Q‡	11·56	11·75	11·68	11·53	11·49	11·41

† One freakishly low year (1958, 10·1 per cent) excluded
‡ *GM* = 11·55; *VR* [*d.f.* = 5 and 34] = 0·0802/0·1323 = 0·61

Effect of new varieties on total crop

An attempt is now made to estimate the overall effect of new varieties on the crop, basing the calculations essentially on the plant crop yields summarized in Figure 2. Study of aggregate yield data for the island and of more detailed figures for transitional periods suggested the rule that yield over all crops could be well approximated by plant yield minus x, where x was about 6.3 t/ha up to 1955 and 12.5 t/ha thereafter. Then, knowing areas under cane and patterns of varietal replacement, and using the plant crop yields (actual and constructed) of Figure 2, the varietal component of increasing yield can be estimated (Figure 3). Taking the nobles (N) as base, the additional crop annually attributable to new varieties rose from about 0.1 Mt due to the T canes to about 0.25 Mt when the F canes were fully established.

The gains due to new varieties may be thought of in relation to their immediate predecessors or to a more remote base (Table 5). The former view attributes a permanent gain to a new variety even though it may have disappeared from cultivation; old varieties long outclassed are thus heavily weighted (e.g. T in Table 5); the latter view sets new varieties against standards with which they never actually competed and is to this extent unrealistic. There appears to be no simple answer to this, the problem of assessing the relative success of non-contemporary varieties. There is no doubt, however, of the collective success of the three cycles of Barbados canes; they added about 23 percent to crop over the whole period. Current gains, due to the S canes, are as great as ever in absolute terms and (because average yields are low) relatively larger than before; but they show up best in poor conditions and their average advantage over their immediate predecessors (F) is

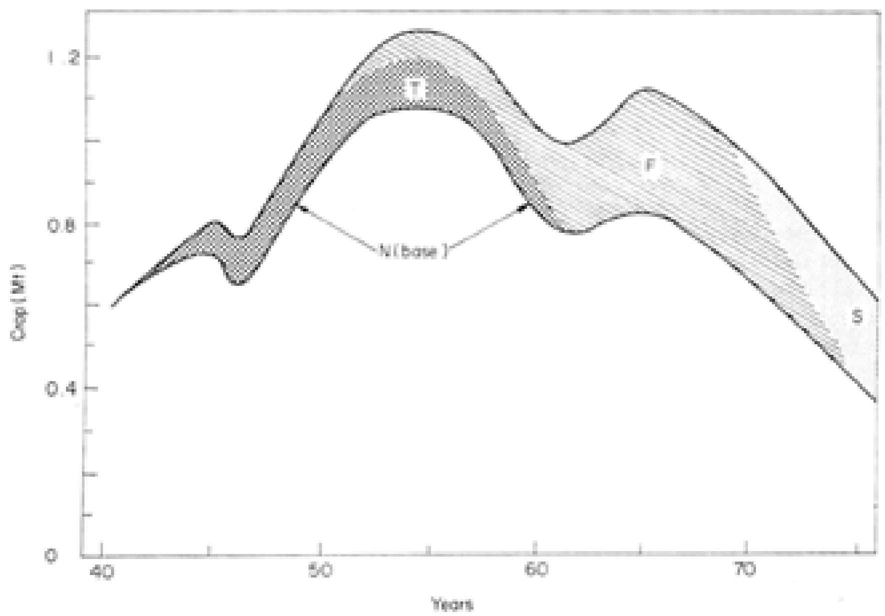


Figure 3. The contribution of breeding to the Barbados sugar-cane crop. Shaded areas are increments of crop over the calculated Noble (N) base attributable to three cycles of new varieties. See text and Table 5

Table 5. Estimated total gains (Mt) to the Barbados sugar-cane crop due to plant breeding, 1940-76

Gain	Cycle		
	T	*F*	*S*
Over predecessor	4·00	2·63	0·05
Over base	1·82	3·65	1·21
Base (Noble) total for 37 years	= 28·80 Mt		
Gains due to plant breeding	= 6·67 Mt		
Total crop	= 35·47 Mt		
Gain over base, per cent	= 23·2		
Gain, per cent per annum (36 years)	= 0·64		

small. In practice, their longer ratooning (Table 2) may be more important economically than a comparatively modest yield advantage.

DISCUSSION

There are four points to make. They concern: the biological advantages of the new canes, their economic effects, the importance of genotype—environment (GE) interactions and longer-term implications for cane breeding.

The principal advance has clearly been in cane yield sustained over crops; there may have been a slight reduction in the rate of yield decline over crops but this is unproved and there is no evidence, either way, for any change in quality (i.e. sugar percent cane). Breeding has therefore primarily affected crop biomass, there being no evidence for enhanced partition. In many other crops, changed partition (towards product, away from crop waste) appears to have been a more important component of rising yields than biomass per se (SIMMONDS, 1979, Chapter 3).

This study provides a basis for an economic analysis, in cost-benefit terms, of the effects of cane breeding, freed by the form the calculations take, of the confusing effects of changing husbandry and weather. Such an analysis, however, would not be easy because it would have to take account, not only of enhanced sugar production per unit area, but also of altered costs of production (including ratooning capacity and the lengthened replanting cycle). There is a growing interest in analysing the economic consequences of applied research and several plant breeding programmes have been shown to be highly successful [short review and references in Simmonds (1979), Chapter 10]. Barbados cane breeding is certainly in this category and it is to be hoped that some interested economist will take the matter up. The impact of canes bred in Barbados certainly goes far beyond Barbados and any serious analysis would have to take a wide view of the matter.

At an admittedly rough computation, the total increment of sugar due to Barbados breeding is probably about 4 Mt over a 30 to 40 year period. EVENSON (1977) (see also EVENSON and KISLEV, 1975) has concluded, by means of production—function analysis, that cane research has indeed been highly productive but the work does not separate breeding from other research components.

The idea of using regressions of individual varieties on trials means, as a measure of adaptation in plant breeding programmes, was advanced by FINLAY and WILKINSON (1963), was later elaborated by EBERHART and RUSSELL (1966) and has since gained fairly wide currency. Briefly, low slopes ($b < 1$) indicate the widely adapted, 'stable' variety, unit slopes ($b = 1$) the average variety and steep slopes ($b > 1$) the narrowly adapted variety responsive to good conditions. A slope other than unity indicates the variety that shows a pronounced GE interaction (see HILL, 1975 for review). It has often been suggested that breeders should prefer one type or the other (usually the stable kind with $b < 1$). In practice, serious selection is hardly feasible and it is left to farmers to find the appropriate niche for a new variety. The idea of using regressions to compare individual varieties (or, as here, small groups of related varieties) is less familiar (discussion and sugar cane example in SIMMONDS, 1979, Chapter 6). There are two aspects, namely comparisons of stability of yield and of yield itself. From the adjusted regressions given above we have the following mean regressions as measures of stability:

$$F(1.16) > T(1.06) = N(1.06) > S(0.78)$$

There is no simple historical sequence but we might speculate that the responsive F and T canes were adapted to the improving environments of their times, the 'stable' S canes to the declining conditions of recent years (Figure 3). As to yields per se, it will be obvious that only when $b = 1$ can a difference be described by a simple mean and only when $a = 0$ by a single percentage figure. Here we touch upon the trials problem mentioned in the introduction: the only evident method of testing the indeed universal (but so far untested) assumption to the effect that trials predict agricultural performance is by examining the colinearity of trials and agricultural regressions. These Barbados data provide (so far as can be ascertained) the first occasion on which such a test has become possible and results will be reported in due course.

Finally, there is the question of long-term progress in cane breeding. For the past 15 years, cane breeders all over the world have been conscious that the genetic base of the crop was narrow (as evidenced by pedigree studies), that the marvellous achievements of the thirties and forties would not readily be repeated and that there was a fairly urgent need to widen the genetic base.

This is in hand in many programmes but decisive results have yet to emerge. On the basis of informed guesswork, one might suspect that future advances will resemble those of the recent past, though maybe individually of lesser magnitude. That is, biomass and maintenance of biomass over crops (including, of course, disease resistance as a component) will be the principal elements; sucrose content must be maintained but is probably now so near a physiological limit that substantial improvement can hardly be expected.

ACKNOWLEDGEMENTS

The author is indebted to Mr D. I. T. Walker, West Indies Central Sugar Cane Breeding Station, Barbados, for many helpful discussions and much advice; and to Dr H. D. Patterson, ARC Unit of Statistics, Edinburgh, for drawing attention to alternative forms of regression equations.

(Received September 1978)

REFERENCES

B.S.P.A. (1973). Notes on the Barbados Sugar Industry. Barbados Sugar Producers' Association, Bridgetown, Barbados

DAVIDSON, B. R. (1965). 'Significance of difference between variety yields under experimental and farm conditions'. Nature (London) 207, 1009

DAVIDSON, B. R. and MARTIN, B. R. (1965). 'The relationship between yields on farms and in experiments'. *Aust. J. Agric. Econ.* 9, 129-140

EBERHART, S. A. and RUSSELL, W. A. (1966). 'Stability parameters for comparing varieties'. Crop Sci. 6, 36-40

EVENSON, R. E. (1977). 'Cycles in research productivity in sugar cane, wheat and rice'. In Resource Allocation and Productivity in National and International Agricultural Research. (Eds Arndt et al.). University of Minnesota Press, Minneapolis, pp. 209-236

EVENSON, R. E. and KISLEV, Y. (1975). Agricultural Research and Productivity. Yale University Press, New York

FINLAY, K. W. and WILKINSON, G. N. (1963). 'The analysis of adaptation in a plant breeding programme'. *Aust. J. Agric. Res.* 14, 742-754

HILL, J. (1975). 'Genotype-environment interactions - a challenge for plant breeding'. *J. Agric. Sci. Camb.* 85, 477-494

HUDSON, J. C. (1973). 'Fire, water and sugar production in Barbados'. Proc. Meet. West Indies Sugar Technol., Barbados, pp. 139-146

MCCOLL, D. (1971). 'West Indian sugar cane varieties'. Bull. West Indies Cent. Sugar Cane Breeding Sta., Barbados

RICKER, W. E. (1973). 'Linear regressions in fishery research'. I. Fish. Res. Board Can. 30, 409-434

SAINT, S. J. (1954). 'Sugar production in Barbados during the past 100 years'. Proc. Int. Soc. Sugar Cane Technol. Gongs., Barbados, 8, 966-977

SIMMONDS, N. W. (1973). 'Optimal replanting time for sugar cane'. Int. Sugar 1. 75, 107-108

SIMMONDS, N. W. (1975). 'Sugar canes'. In Evolution of Crop Plants, pp. 104-108. Longman, London

SIMMONDS, N. W. (1976). 'Progress in sugar cane breeding'. LS.S.C.T. Sugar Cane Breed. Newsl. 38, 75-78

SIMMONDS, N. W. (1979). Principles of Crop Improvement. Longman, London

SMITH, S. I. (1976). 'Sugar production potential in Barbados'. 3. Trap. Geogr. 42, 59-77

SPRENT, P. (1969). Models in Regression and Related Topics. Methuen, London

STEVENSON, G. C. (1952). 'The Barbados sugar cane varieties'. Bull. B. W.I. Cent. Sugar Cane Breed. Sta., Barbados

STEVENSON, G. C. (1960). 'Sugar cane varieties in Barbados. An historical review'. Bull.

B. W.I Cent. Sugar Cane Breed. Sta., Barbados, 37

STEVENSON, G. C. (1965). Genetics and Breeding of Sugar Cane. Longman, London

VARIOUS AUTHORS (1936-76). 'The yields of sugar cane in Barbados'. Department (later Ministry) of Agriculture, Barbados, annually

Extracted from Volume 61, Number 2, 1984

Modern systems of fruit growing and their application for the improvement of tropical fruit production

Shafaat Mohammed and Lawrence A. Wilson

Department of Crop Science, University of the West Indies, St Augustine, Trinidad

Received May 1983; revised August 1983

Modern fruit growing systems such as Bush Orchard. Meadow Orchard, the Tatura Trellis, Pyramid. Cordon. Curtain and the Hedgerow are described. A comparison is drawn between the modem systems and the traditional system of fruit growing. In addition to early cropping and returns on investment, high regular yields and low labour requirement, the modern systems of fruit growing offer several advantages over the traditional system. The feasibility of applying these new systems of fruit growing for the improvement of tropical fruit production (with special reference to the research at the University of the West Indies into the development of the Meadow Orchard system for guava production) is mentioned.

Keywords: Fruit; Production; Growing systems

Modern systems of fruit growing which have been developed over the years for temperate fruit production (Fig. 1) can be employed for tropical fruit production with certain modifications. These systems basically involve the planting of small trees densely. controlling growth by chemicals, dwarfing rootstocks, pruning and training; and, in some cases, harvesting by machine. This development in the area of horticulture took place gradually from relatively few large trees per hectare grown on seedling rootstocks through many intermediate forms to high density planting systems with many pindle-type trees per hectare on dwarfing root-stocks. The reason for this change was the necessity to achieve early cropping, high regular yields and low labour requirement to meet continually rising production costs. Comparisons between these modern systems and the traditional systems of fruit growing indicate that the former systems offer several advantages over the latter (Table 1). Moreover, the few disadvantages of modern systems of fruit growing may be solved by research.

Although modern systems of fruit growing have become popular and are being used on commercial scales for temperate fruit production, their potential and usefulness in the field of tropical fruit production still remain unexploited. At the same time, the traditional system of fruit growing is proving to be inefficient, unattractive and unmanageable and is contributing to a decline in tropical fruit production, particularly in areas of high labour cost.

There is urgent need for improving and modernizing the traditional system of tropical fruit growing. This Paper describes various modern systems of temperate fruit growing and examines the feasibility of utilizing such systems in the improvement of tropical fruit production.

Classification

The modern systems of fruit growing described here could be classified (Fig. 1) on the basis of density or intensity of planting, as medium high density planting (mhdp), optimum high density planting (ohdp), and maximum or ultra-high density planting (uhdp). However, classification of these systems on the basis of shape, size and form of trees such as Bush, the Tatura Trellis, Pyramid, Cordon, Curtain, Hedgerow (fruit wall or tree wall) and Meadow Orchard seems

0041-3216/2021/030265-272

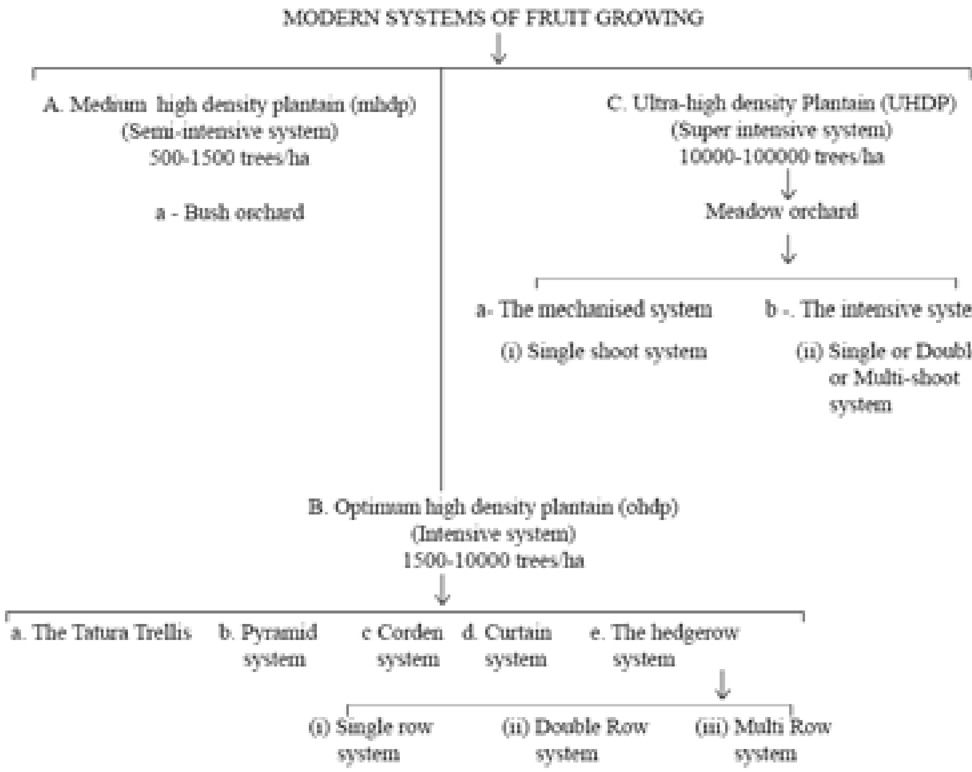


Fig. 1 Schematic illustration of various modern systems of fruit growing

Table 1 Comparisons between traditional systems and modern systems of fruit growing

Attribute	Traditional systems	Modern systems
Tree number	Few large trees ha^{-1} (≈ 150–200 trees ha^{-1})	Many small trees ha^{-1} (≈ 500–100 000 trees ha^{-1})
Bearing	Late in bearing: usual time required is 6–8 years or more	Precocious in bearing: usual time required is 2–3 years
Production	Overall production per hectare is low (≈ 15–25 t ha^{-1})	Increased overall production per hectare (≈ 30–50 t ha^{-1})
Management	Difficult to manage due to large size of trees	Easy to manage small trees
Labour	Requires more labour	Requires less labour
Production cost	Higher cost of production	Reduced cost of production
Harvesting	Difficult (Manual)	Easy by machine
Quality	Large canopy, poor sunlight penetration and poor quality	Small canopy, better sunlight penetration and a better quality
Establishment cost	Low	High
Machinery	Does not require expensive machines	Requires expensive machines
Chemical or growth substance	Not essential to use growth substances to control growth, flowering and fruiting	Requires the use of growth substances for control of flowering and fruiting

to be more common. This latter classification is used here, but reference is also made to plant density in the description of systems of fruit growing.

Description

Bush Orchard

The Bush Orchard is a semi-intensive or medium high density planting system of fruit growing with a plant density of 500-1500 trees ha^{-1} (as against 120 or 177 trees ha^{-1} in the traditional system) in which the tree resembles a bush. Either a dwarf cultivar or dwarfing rootstocks are used to control tree height. The modified central leader or any other suitable system of training is used. Light pruning in early years, consisting of thinning of branches around the trees after harvesting, and moderate pruning in late years, are carried out to restrict tree growth. Organic and inorganic fertilizer applications are used to ensure high fruit yield.

The advantage of Bush Orchard or the semi-intensive system of fruit growing is the lower cost of orchard establishment compared with ohdp and uhdp systems. This system is particularly important where land availability is not a limiting factor and for cultivars which are not suitable for intensive systems. For example, in the UK the main apple cultivar, Cox's Orange Pippin, proved rather difficult to handle under intensive systems. It should be noted, however, that bush or semi-intensive systems take a longer time (4-5 years) than intensive systems to give substantial returns; and pruning, hand thinning and harvesting operations are more intensive.

Tatura Trellis

The Tatura Trellis is a close-planting high density or intensive planting system, with rows of V-shaped trees running north-south. Each tree has only two limbs which grow east and west at an angle of ≈ 60° to the horizontal. This system of fruit growing was developed at the Irrigation Research Institute, Tatura, Australia in 1973. Results indicated that early and high yields were possible (Chalmers & van den Ende, 1975; van den Ende & Chalmers, 1982) and a number of orchardists established trial plantings of the Tatura system under commercial conditions. Cumulative yields in commercial planting of clingstone peach trees trained on the V-shaped Tatura Trellis system (average density 1800 trees ha^{-1}) were 145 t ha^{-1} after five growing seasons as compared with 52 t ha^{-1} in commercial low density orchards with conventional vase-shaped trees (average density 300 trees ha^{-1}). The system increases returns on investment and allows fruit farmers to respond more quickly to changes in the relative profitability of fruit crops and cultivars.

Pyramid Orchard

This is an intensive or high density planting system of fruit growing in which trees are planted at densities up to 3000 trees ha^{-1}. The trees are trained as a centre-leader pyramid having height and maximum spread measurements of 4 m. To avoid problems with spray penetration, shading of fruit-bud formation, poor fruit colour and difficulties with harvesting, fruit thinning etc., the trees should have a multi-canopy pattern with a very open texture.

On less fertile soils the pyramid system seems to prove beneficial (McKenzie, 1980). Already, very heavy yields of apples (130-170 t ha^{-1}) are being produced under this system in New Zealand. The system is also suitable for trees that require no support and summer pruning.

Cordon system

The Cordon system is used in France for peach culture using seedlings as rootstocks (Hugard. 1980). The most common planting distance is 4 x 1 m (2500 trees ha^{-1}). With peach it is not absolutely necessary to have a wire and stake device for maintaining the trees. Strong, regular and feathered trees during the first year in the orchard can be obtained by cutting down the yearling tree ≈ 10 cm above the bud union at the planting time during the first two years of the orchard life, it is important to remove the basal lateral shoots of the tree, which have a tendency to become too strong. and to leave the main vertical shoot, thus realizing the cordon shape.

Control of tree vigour is very important during the first two or three years. If the tree is too vigorous, fruit set is very low and the trees produce many water shoots; but when trees are too weak, they remain small and unproductive. In the cordon system, trees are 4-5 m high at the age of four years. Fruit production begins in the second year and full bearing is achieved in the fourth or fifth year.

Curtain system

This system of fruit growing is based on mechanization of harvesting and pruning, and was developed in Hungary by Gyuro et al. (1980) for apple growing. The mechanization of apple harvesting needs a tree with flexible yield-holding twigs and as few as possible rigid skeletons. The skeleton of the curtain is a central leader with one or two pairs of horizontal scaffolds. 180 cm and 220 cm long, in a tree density of 3000 ha^{-1}. The cropping twigs hang vertically to give a hanging twig-curtain which accommodates the horizontally vibrating fingers of the fruit harvester. Tree flexibility is very important because both the vibrating fingers and the fruit collecting devices penetrate into the tree canopy. The maximum height of the tree is usually 3.2 m.

The apple-Curtain system, using an over-row harvester, increases efficiency in apple growing without any loss in investment and yield. Cultivars with long, thin and prolific shoots perform best, The first Hungarian apple-Curtain plantings have about the same yield as hedgerow orchards of the same age and density but the size and colour of fruits are better because the curtain is thinner.

Hedgerow system

The Hegderow (fruit wall or tree wall) system is the most common modern system of fruit growing used for apple. pear and peach production. It is based on the use of growth regulators combined with root competition to reduce the size of trees, and is designed primarily for mechanized harvesting by an over-row harvester. In this system the trees are planted at a spacing of 30 or 50 cm apart in the row and 3 m between the rows with a tree density ranging from 2500 to 10 000 ha^{-1}. The trees are supported on wires and are trained as vertical cordons grown to a height of 2 m. Further growth is stopped by the application of ‘Tree-hold’, a commercial formulation of 1% naphthalene acetic acid in bitumen. The lateral growth of the trees into the alley-ways is controlled by mechanical pruning with a hedge trimmer combined with the use of SADH (succinic acid-2, 2-dimethyl hydrazine*). The effect of the growth retardant is to arrest the growth of the shoots which grow out following mechanical pruning and to induce fruit buds on shoots. In this way the growth of the trees can be contained and annual crops of high quality fruit obtained from the second year onwards.

The trees can be planted either in single, double or multi-row systems. The major advantage of the single row design is an improved light distribution within the canopy which is desirable for good fruit quality as well as for easy orchard management in the many alley-ways. A distinct drawback is that with very high tree numbers within the row, the light interception is far from maximal through the many alleys and hence the yield capacity of the orchard is reduced. Moreover, average fruit size may also be reduced when tree distances within the row become small. With multi-row systems both light interception and the production potential of the orchard increase, but light distribution and average fruit colour may become less optimal. With increase in the number of trees ha^{-1}, the sample space per tree derived from the sacrifice of alleys is reduced. Thus, one of the major advantages of the multi-row system is lost and average fruit size and colour may be reduced. Further disadvantages are the poor accessibility of the canopy for management and poor penetration of spray droplets compared with single rows. The latter disadvantage can lead to higher incidence of diseases in the middle sections of the multi-rows.

Meadow Orchard

The Meadow Orchard is a super-intensive or ultra-high-density planting system in which the fruit plants are grown at densities of 20 000-100 000 ha^{-1}.

The general concept of the Meadow Orchard has been described by Hudson (1971) and progress in solving some of the technical problems is recorded by Child (1972), Luckwill and Child (1973) and Luckwill (1978). This system is designed to produce fruit on two-year-old plants which are chemically disciplined and regulated to produce a simpler and smaller structured framework rather than the traditional well-branched trees. In the apple, plants are induced to form fruit buds in their first year by growth-regulator treatment. In the second year, plants flower and produce fruit, after which they are cut back to a stump from which a new shoot is regenerated to repeat the biennial cycle. Ultimately, harvesting is carried out by mowing the orchard (hence, the term ‘meadow’) with some form of combine harvester which would separate fruit from the shoots.

*Also known as Diaminozide. Alar and B-nine are trade names

The original Meadow Orchard system developed for apples is designed for mechanical harvesting, which provides an advantage on a large farm, but may not suit the small family farm because of the high cost of the machinery required. However, the advantages of an orchard of small trees that can be handled from the ground, has reasonable establishment and is very precocious in cropping, are quite attractive for the small grower who picks his fruits manually. Hence, Erez (1982), working with peaches, developed two feasible systems of Meadow Orchard, i.e. the mechanized system for a large farm and the intensive system for the small family farm.

The mechanized system

This system is developed for mechanized harvesting using a combine harvester that separates the fruit from a cut canopy. The idea is to detach the stem of the tree at harvest, leaving only a short stump from which regrowth would begin. The rest of the sequence of events is almost the same as described earlier. The mechanized Meadow Orchard (peach) has two main drawbacks: it is not suitable for cultivars ripening in mid- and late-season, due to insufficient time for top regeneration. The shock to the plant with complete removal of the green canopy is also very severe, accentuating latent problems such as a low level of certain elements, which lead to severe deficiencies. Continuous supply of these elements through the irrigation system can overcome this problem.

The intensive system

In this new Meadow Orchard system, the pruning is separated from harvesting by delaying it until after harvest. The tree is trained to two main shoots rather than one, as in the mechanized system (Fig. 2). One of the two shoots is headed back to a stump, allowing regeneration of new growth and flower bud formation in the course of the growing season.

The other shoot is not pruned; it fruits and is headed lightly after harvest to reduce shading on the adjacent growing shoot and is pruned to a short stump thereafter. Therefore, every shoot fruits every second year. In this system. annual fruiting could be obtained independent of time of harvest and the shock to the plant is reduced considerably by shifting the canopy topping.

Two main problems emerge with this system: one is how to obtain new vigorous annual growth from the shaded lower part of the tree; and the other is how to prevent shading of the lower part of the developing shoot by the remaining uncut shoot to allow development of flower buds along the entire new shoot. These problems can be overcome by manipulating the pruning. Yield of trees managed by the intensive system increases considerably in comparison with the mechanized system, due to increases in flower bud differentiation, fruit set, and yield per tree over the mechanized system. Enhanced fruit ripening is also achieved. Both systems have the advantages of precocious bearing, independence of tree support, and in the relatively simple and inexpensive means of orchard establishment from rooted cuttings. This makes commercialization of the two systems feasible. The Meadow Orchard system may not be beneficial for those fruit crops which are difficult to propagate by cuttings because of initial high cost of establishment as well as the problems of sprouting in rootstocks.

Application in tropical fruit production

Although a large number of tropical fruit species exist, only traditional fruits (citrus and banana) and plantation crops (cacao, coffee, coconut) are grown on commercial scales (Table 2). Most other tropical fruits, such as avocado, mango. papaya, guava, cashew, sapodilla, soursop etc., are grown as backyard trees. Moreover, production of traditional tree crops is declining. Thus, it appears that tropical tree crops, particularly non-traditional species, have remained neglected and unexploited despite their great potential.

In addition to the problems of post-harvest handling, processing and marketing, the following problems seem to have hindered the progress and development of non-traditional tree crops and have led to the decline in production of traditional tree crops:

(1) lack of modern and efficient systems of growing tropical tree crops;

(2) scarce and costly labour, particularly in the Caribbean countries;

(3) loss of competitive advantage of low cost of production. In fact. the Caribbean is perhaps the region with the highest cost of production of tropical fruits.

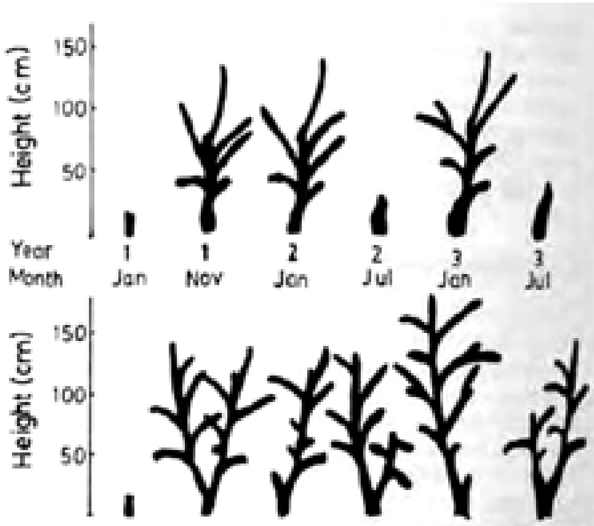


Fig. 2 A schematic comparison of tree development under the mechanized (upper) and the intensive (lower) system of Meadow Orchard (Erez, 1982)

There is clearly a need to introduce highly productive, intensive and mechanized systems of fruit production in tropical countries, especially in the Caribbean. Tropical fruit production could be greatly enhanced both in quantity and quality by using modern systems of fruit growing; failure to employ such systems may continue to contribute to the decline of traditional tree crops and under exploitation of non-traditional tree crops. Research is needed to study possible application of modern systems to tropical fruit species.

Unfortunately, little research is being carried out in different parts of the world to improve fruit growing systems, but research carried out in the past indicates that various modern systems of fruit growing can be employed beneficially for the production of tropical tree crops such as citrus, guava, cacao and coffee. For instance, Boswell (1977) reported that in citrus (‘ Naval’ orange) denser planting increased total yield per acre. More recently. Hutton (1980) in Australia. and Trelistskaya (1981) in the Soviet Union tried semi-intensive and intensive systems of Fruit growing for citrus (‘Valencia’ and ‘Hamlin’ oranges) and obtained higher yields. Similarly, Chapman et al. (1979) induced

Table 2 Important traditional and non-traditional tropical tree crops grown in the tropics

Common name	Botanical name	Family
Traditional		
Cacao	*Theobroma cacao* L.	Sterculiaceae
Coffee	*Coffea* spp.	Rubiaceae
Coconut	*Cocos nucifera* L.	Palmae
Citrus		
Orange	*Citrus sinensis* (L.) Osbeck	Rutaceae
Grapefruit	*Citrus paradisi* Macf.	Rutaceae
Mandarin	*Citrus reticulata* Blanco	Rutaceae
Lime	*Citrus aurantifolia* (Christm.) Swing	Rutaceae
Lemon	*Citrus limon* (L.) Burm. f.	Rutaceae
Banana	*Musa* cultivars	Musaceae
Non-traditional		
Avocado	*Persea americana* Mill.	Lauraceae
Mango	*Mangifera indica* L.	Anacardiaceae
Papaya	*Carica papaya* L.	Caricaceae
Cashew	*Anacardium occidentale* L.	Anacardiaceae
Guava	*Psidium guajava* L.	Myrtaceae
Sapodilla	*Achras sapota* L.	Sapotaceae
Soursop	*Annona muricata* L.	Annonaceae
Custard apple	*Annona reticulata* L.	Annonaceae
Sweet-sop (Sugar apple)	*Annona squamosa* L.	Annonaceae
Bread-fruit	*Artocarpus altilis* (Park.) Fosberg	Moraceae
Ackee	*Blighia sapida* Koenig	Sapindaceae
Nutmeg	*Myristica fragrans* Houtt.	Myristicaceae
Carambola	*Averrhoa carambola* L.	Oxalidaceae
Mammee sapote	*Calocarpum sapota* (Jacq.) Merr.	Sapotaceae
Tamarind	*Tamarindus indica* L.	Leguminosae
W.I. cherry	*Malpighia glabra* L.	Malpighiaceae
Indian jujube	*Zizyphus mauritiana* Lam.	Rhamnaceae
Jackfruit	*Artocarpus heterophyllus* Lam.	Moraceae
Litchi	*Litchi chinensis* Sonn.	Sapindaceae
Mangosteen	*Garcinia mangostana* L.	Guttiferae
Pomerac	*Eugenia malaccensis* L.	Myrtaceae
Jambolan	*Eugenia cuminii* (L.) Druce	Myrtaceae
Star apple	*Chrysophyllum cainito* L.	Sapotaceae
Durian	*Durio zibethinus* Murr.	Bombacaceae

early cropping of guava seedlings in a closely planted orchard (805 trees ha^{-1}) using a 25% urea defoliation spray. Singh et al. (1980) studied a medium high density planting system (Bush Orchard) of fruit growing for guava and obtained higher yields. Freeman (1975) advocated close planting of cocoa in early years and demonstrated a four-fold increase in yield. The trend for closer planting of coffee is already being exploited in many coffee-growing countries (Narasimhaswamy, 1968: Kabaara, 1969); very high density planting for coffee has proved successful in Puerto Rico (Vicente-Chandler et al., 1968; van Rest. 1968) and this is being investigated in Kenya (Huxley. 1970). These research findings suggest that there might be potential for application of some of the modern techniques of fruit production in tropical fruit species, but the application of such modern systems as the Hedgerow and Meadow Orchard must await more research and developmental work.

Recently, a research project has been initiated by the authors at the University of the West Indies, Trinidad. to develop a 'Meadow Orchard' system for guava production using the processing cultivar 'Centeno prolific' (Fig. 3). This research project involves the planting of rooted guava cuttings at three ultra-high densities (27 000, 37 000 and73 000 trees ha^{-1}) and studying the effects of several plant growth regulators (daminozide, ethephon, chlormequat, NAA, PP333, etc.) at different (250 - 3000 ppm) concentrations on growth, flowering and fruiting. Although it is too early to predict the feasibility of using the Meadow Orchard system on a commercial scale for guava production , preliminary results are quite encouraging. Not only was fruiting obtained in the first year of planting but estimated yield, as high as 27 t ha^{-1},was recorded in one of the treatments which far exceeds the yield (10.8 t ha^{-1}) obtained four years after planting under traditional systems (Singh et al., 1980). This encouraging performance of guava under the Meadow Orchard system suggests that commercial application may become a reality in the near future.The new orchard systems such as the Hedgerow, Cordon and Curtain appear to be equally attractive and promising for guava production , but require intensive research for their development. At present, the application of the Meadow Orchard and other high density planting orchard systems for production of mango, avocado, cashew, sapodilla, etc. seems not to be easy because of the difficulty of vegetative propagation by cuttings in these fruit crops. Research has also been initiated to remove this and other constraints to the application of modern fruit growing systems in as many tropical fruit crops as possible. It may be appropriate to mention that the main stimulus to the development of intensive and semi-intensive systems of apple production in temperate climates was the development of dwarfing and semi-dwarfing rootstocks. The absence of such rootstocks for tropical fruits has undoubtedly been a major inhibiting factor in the past. Now that chemical dwarfing and the production of dwarf mutants by irradiation are possible, a new field of research is opened up which may help develop modern systems of fruit growing in tropical fruit species.

Fig. 3 A partial view of the field trial of 'Meadow Orchard' being developed by the authors for guava cv. 'Centeno Prolific' (Processing cultivar). Plot 6 in the photograph shows a plant density of 37 000 plants ha--1 (90 x 30 cm spacing)

Conclusions

The development of modern systems of fruit growing marks an important breakthrough in the field of fruit production. These modern systems have almost revolutionized fruit production by providing precocity and increased productivity coupled with a reduction in production cost and labour demand. The choice and success of various systems (Pyramid, Cordon. Hedgerow, Meadow Orchard, etc.) will depend on economical, technical. climatic as well as soil conditions and on the behaviour of the fruit species and cultivars. Increasingly, some of the modern systems of fruit growing are being used on commercial scales in Europe and USA for temperate fruit production. Unfortunately, modern systems of fruit growing, particularly high density and ultra-high density planting systems (the Hedgerow, Meadow Orchard), still remain unexploited in the field of tropical fruit production, despite their apparent potential. Attempts are now being made to study the application of these systems for improvement of tropical fruit production. In Trinidad, research results indicate that the Meadow Orchard system appears quite promising for guava fruit production. However, further research is needed before the system can become fully applicable on a commercial scale.

Acknowledgements

The authors wish to acknowledge support for the project in terms of a research grant from the Government of Trinidad & Tobago to the Faculty of Agriculture, University of the West Indies.

References

Boswell. S.B. (1977) High density for early yield. Citrograph 62 182

Chalmers, D.J. and van den Ende, B. (1975) The 'TaturaTrellis': a new design for high yielding orchards. *J. Agr. Vic.* 73 473-476

Chapman. K.R., Saranah, J. and Paxton. B. (1979) Induction of early cropping of guava seedlings in a closely planted orchard using urea as a defoliant. *Aust. J. Exp. Agric. Anim. Husb.* 19 382-384

Child. R.D. (1972) Meadow orchard workable but still many problems to solve, The Grower 77 179-181 Erez, A. (1982) Peach meadow orchard: Two feasible systems, *Hort Science* 17 138-142

Freeman. W.E. (1975) A possible new approach to cocoa growing. Ministry of Agriculture. Lands & Fisheries ofTrinidad & Tobago Publications. pp 13

Gyuro, F.. Velich, S., Geiszler, J. and Sipos, B. (1980) Apple-curtain system for mechanization. Symp. Res.

Develop. Orch. Plant Syst. Lana (3-9 August). pp. 255 Hudson, J.P. (1971) Meadow orchards, *Agriculture* 78 157-160

Hugard, J. (1980) On peach density planting in France. Symp. Res. Develop. Orch. Plant Syst. Lana (3-9 August), pp. 255-256

Hutton. R.J. (1980) High density citrus plantings. Farmers Newsletter No. 148 18-19. Agri. Res. Centr. NSW,Australia

Huxley. P.A. (1970) Some aspects of the physiology of arabica coffee - the central problems and the need fora synthesis, in: Physiology of Tree Crops (Eds L.C. & Cutting. C.V.) London: Academic Press, pp. 255-267

Kabaara. A.M. (1969) Some aspects of current coffee production in four south and central American countries. *Kenya Coff.* 34 31-39

Luckwill, L.C. (1978) Meadow orchard and fruit walls, *Acta Horticulturae* 65 237-243

Luckwill. L.C. and Child. R.D. (1973) The meadow orchard - a new concept of apple production based ongrowth regulators, *Acta Horticulturae* 34 213-220

McKenzie, D.W. (1980) The ideal apple tree unit in NewZealand, Symp. Res. Develop. Orch. Plant. Syst. Lana (3-9 August), pp. 254

Narasimhaswamy, R.L. (1968) Production of coffee in India during the next decade. *Indian Coff.* 32 332-336 Singh. I.S.,

Singh, H.K. and Chauhan, K.S. (1980) Effectof high and low density plantation on yield and quality of guava under semi-and conditions, *Haryana Agric. Univ. J. Res.* 10 421-423

Trelitskaya, E.G. (1981) Some results of work on the optimal density and spacing pattern for Hamlin orange trees, Subtropicheskie Kultury No. 1 18-22 (Russian)

van den Ende, B. and Chalmers, D.J. (1982) An evaluation of commercial experience with the Tatura Trellis for growing peaches. *Hort Science* 17 218-220

van Rest, D.J. (1968) Coffee harvesting and conceptual problems of mechanization, World Crops 19 19

Vicente-Chandler. J., Abruna, F., Lugo. R.B. and Silva, S.(1968) Intensive coffee culture in Porto Rico, *Bull.*

Porto Rico. Agric. Exp. Stn. Insular Stn Rio Piedras No 211

Extracted from Volume 65, Number 4, 1988

Agronomic research on cocoa in Jamaica 1950-1980 and current research trends

H.J. Fagan and B.F. Toppert*

Faculty of Agriculture Unit, University of the West Indies, Mona, Jamaica, W.I.

Received October 1987; revised March 1988

Agronomic research in cacao in the 1950s in Jamaica was devoted almost entirely to the introduction, propagation and establishment of different varieties imported mainly from Trinidad and St Vincent. Field evaluation of these introductions led to the adoption of a few medium- to high-yielding varieties, but the later discovery of their susceptibility to black pod disease [*Phytophthora palmivora* (Bull.) Bud.] restricted their use as parents in breeding programmes. The resulting germplasm base of the cocoa industry is very narrow. However, the observed slow growth of the pathogen in the pod tissues of the susceptible variety ICS 60 permitted its use and resulted in the production of PA 150 - ICS 60 as the best-yielding local hybrid. Nutrition experiments dealt mainly with the effects of N, P and K on yield of cocoa cultivated with or without shade, and with liming of acid soils. but no experimentally determined fertilizer recommendations ensued. New fertilizer experiments aim to address this, and other current research seeks to broaden the germplasm base of the cocoa industry and to re-evaluate a cocoa/coconut intercropping system.

Keywords: Cacao: Jamaica

Cocoa (*Theobroma cacao* L.) has been grown in Jamaica since the 17th century (Fagan, 1984), but although it was in Jamaica that F. Harris pioneered the successful budding of cocoa by his patch budding technique in 1902 (Van Hall, 1914), very little agronomic research was undertaken there until the late 1940s; patch budding had not been adopted. The improvement of Jamaican cocoa germplasm relied heavily on results of research undertaken at the well-established former Imperial College of Tropical Agriculture (I.C.T.A. - now the Faculty of Agriculture of the University of the West Indies) in Trinidad.

There has been a long history of cocoa research at I.C.T.A. where Pyke in 1935 first developed the method of cocoa propagation by rooted cuttings (Topper, 1957a). The renowned Imperial College Selections (ICS vacs) of cocoa from that regional institution were made readily available in Jamaica. Thus, in 1942, several of these varieties, ICS 1, ICS 6, ICS 8, ICS 45 and ICS 98, were established in Jamaica from budwood obtained from Trinidad (Anon, 1977). All but one of those selections were Trinitario cocoa (hybrids resulting from crosses between Forastero and Criollo types of cocoa). The exception, ICS 45, was a true Criollo selection.

Cocoa had been regarded as an economically minor crop until the late 1940s when a new thrust towards improving the cocoa industry in Jamaica commenced. In 1947, the Jamaica Department of Agriculture initiated steps for rehabilitating local cocoa cultivations, following the assurance of a ready external market for all the cocoa that could be produced, and recommendations from a 1945 agricultural report on the centralization of cocoa processing on the island. In 1948 the first agronomist to the industry was appointed (Fagan, 1984), and in 1949 a scheme for the expansion of the cocoa industry was approved (Anon, 1950b), which ambitiously aimed at cultivating 20 243 ha (50 000 ac) in 10 years. Almost 40 years later, this ambition is yet to be realized.

* Present address: WINBAN, PO Box 115, Castries, St Lucia, W.I.

+ Cocoa Industry Board, Marcus Garvey Drive, PO Box 68, Kingston 15, Jamaica, WI

0041-3216/2021/030273-279

Cocoa introductions and multiplication of germplasm

Adding to the earlier introductions from Trinidad, budwood of two of the currently highest yielding varieties in Jamaica, namely, ICS 60 and la 95, was imported from St Vincent in 1950 (Anon, 1950a, 1951), and a further eight varieties (GS 29, GS 36, ICS 16, ICS 32, ICS 39, ICS 40, ICS 46 and ICS 84) were imported from the same source in 1956 (Topper, 1957b). In 1957, five more varieties were introduced from Costa Rica, and eleven from Mexico.

Work over the next several years consisted essentially of the multiplication of the introduced varieties by budding, and the propagation of local clones by rooted cuttings. Rooted cuttings of several new varieties were also imported from Trinidad in 1959. These included IMC 57, 1MC 67, PA 30, PA 46, PA 81, PA 121, PA 150, PA 169, PA 218, SCA 6, SCA 9, SCA 12, TSA 644 and TSH 556 (Dow, 1960), some of which are now parents of important hybrid material, and others growing commercially.

Initial technical difficulties encountered in the production of rooted cuttings hampered the propagation drive. These difficulties arose partly from lack of experience in the relevant techniques and partly from the apparent paucity of relevant information then available in the literature (Topper, 1957b). In attempting to overcome these difficulties, a number of small-scale exploratory experiments had been conducted earlier. From such experiments it was determined that a 500 ppm β-indolebutyric acid (I.B.A.) dip of the cuttings produced the best rooting results among various growth-promoting substances tested (Anon, 1951). Some success had previously been obtained also in selecting a satisfactory potting medium and in air-layering (marcottage) (Anon, 1950b). These successes were important advances for undertaking clonal propagation by rooted cuttings on a substantial scale.

During those early years of establishing a germplasm base, while at the same time providing planting materials for an expanding cocoa industry, a rapid expansion of cuttings gardens was undertaken, but with the use of *Gliricidia* sp. as the main source of overhead shade, the long period required for the development of a satisfactory shade canopy resulted in poor establishment of the nurseries. Further, the occurrence of high pH in the soils of some nurseries (sometimes due to presence of free lime) also retarded growth of the young plants. The edaphic difficulties were alleviated to some extent by various cultural and exploratory treatments (Anon, 1951).

By 1956, a large number of local seedlings were being produced in the nurseries, facilitating a novel system of 'budding-at-stake' (budding of seedlings already transplanted in the field), using a method of T-budding developed by Topper (1957a). However, budding-at-stake subsequently failed due to extreme shortage of supervisory extension personnel in the Department of Agriculture, and to high cost of field maintenance (Topper, 1957b; Dow, 1960). The T-budding technique succeeded and was employed in producing over 130 000 plants, these being grown in improvised pots made of intemodes of large bamboo stems as a cost-reducing system.

Despite the continued popularity of rooted cuttings as planting material, by 1959 it had become more practical to distribute hybrid seedlings to growers. This was prompted partly by recent information from researchers in Ghana and I.C.T.A. in Trinidad that hybrid seedlings resulting from crosses between Forastero or Trinitario cocoa and some wild cocoa varieties from the Upper Amazon basin were more vigorous and hardier planting material than rooted cuttings (Anon, 1977). About 1960, a programme was started for producing hybrid seeds locally by hand pollination and open pollination of a selected number of parents. Among the important female parents used were IMC 67, SCA 12, PA 150 and PA 169; the most widely used male stocks were ICS 1, ICS 6, ICS 8 and ICS 60 (Anon, 1964). The open-pollinated hybrids (the most readily available planting material) were obtained from the earlier interplanting of PA 150 with ICS 60 and, separately, with ICS 1 in a seed garden (Anon, 1977). Thus, from 1961 an appreciable number of hybrid seedlings were produced in Jamaica, thereby reducing importations of materials from Trinidad. Over 200 000 open-pollinated hybrid seedlings are currently obtained from the seed garden annually.

The emphasis hitherto had been on high-yielding selections, but with the discovery by Leather (1964, 1966) of high susceptibility to black pod disease (Phytophthora palmivora (Bud.) Bud.) in some of the female parents used in the breeding programme, modifications were effected in the programme. Thus, the large-seeded and vigorous but susceptible IMC 67 variety continued to be used, but only for seedlings to be distributed to areas with low disease incidence. The use of the susceptible SCA 9 and SCA 12 female parents was discontinued although they were believed to confer a distinctive and desirable flavour called `arriba' to their progenies (Anon, 1964).

Research findings in Trinidad and elsewhere had shown that cocoa may yield better under reduced shade (Murray and Herklots, 1955; Cunningham et al., 1961) and that low shade was also conducive to low humidity which is less favourable for black pod disease development (Dakwa, 1974, 1977; Vernon, 1966; Rocha and Machado, 1972). It was therefore correctly argued that removal of overhead shade would reduce the incidence of black pod disease in Jamaica where susceptible progenies were being grown.

Differences in susceptibility to black pod of some of the introduced varieties from Trinidad were confirmed by Spence (1961) shortly before Leather's (1964) discovery of differential susceptibilities under Jamaican conditions. Disease reactions of the same varieties differed between isolates of *P. palmivora* from Trinidad and those from Jamaica; while in Trinidad the Scavina varieties (e.g. SCA 6) were found more disease-resistant than ICS 1 (Spence, 1961), in Jamaica the reverse was found to obtain (Leather, 1964, 1966). The contrasting reactions probably resulted from differences between the strains of *P. palmivora* occurring in the two localities.

Of 39 clones and hybrids subsequently tested (including 17 Jamaican hand-pollinated crosses), appreciable resistance to black pod disease was reported only in ICS 1 and PA 169 in the imported clones, and in JH 10 and JH 17 from the local hybrids (Henry, 1973, 1974). The presence of disease resistance in so few of the tested materials reduced the scope for further field resistance trials. However, a trial was set out in 1972 to evaluate four locally-produced hybrids of some introduced varieties for susceptibility to disease and for desirable agronomic properties (especially bean size and yield). After nine years of evaluation, it was concluded that disease reactions were variable and dependent on weather conditions. The hybrid PA 169 x ICS 1 was found to yield the least, and PA 150 x ICS 60 the most (Reid, 1981).

Varietal trials

The first recorded variety trial was planted in 1949, but it was abandoned after two years due to difficulties in establishing adequate shade and in obtaining a suitably uniform stand of cocoa (Anon, 1951). A new variety trial was started at Orange River Agricultural Station in 1952 using local and introduced varieties grown under banana as temporary shade and *lnga vera* (Willd.) as permanent shade (Topper, 1953). After 10 years, and following the removal of all overhead shade during the preceding three years (Topper, 1964), the yields of the different varieties were finally resolved into three groups: (A) high yielders: ICS 60 and ICS 6; (B) medium yielders: ICS 8, ICS 1, ICS 98 and ICS 95; and (C) low yielders: JCV 1, JCV 2, JCV 3 (all local germplasm) and ICS 45.

Despite the favourable response of ICS 6 and the acceptable performance of the varieties in group B, only ICS 1 and ICS 60 were subsequently actively propagated for distribution, due to the high susceptibilities of the other varieties to black pod disease (Anon, 1977). Despite the known susceptibility of ICS 60, it had been observed that there was a relatively slow invasion of the pod tissues by the pathogen; consequently, many infected pods were still marketable. Thus, ICS 1 and ICS 60 are currently the two most widely grown varieties, although a number of other varieties, e.g. ICS 95, ICS 98 and ICS 6 are also found in commercial quantities.

Nutrition studies

Studies in cocoa nutrition were all conducted at the Orange River Agricultural Station near Highgate in the cocoa-producing parish of St Mary. Highgate clay, a particular category of soil which occurs on the predominant lesser slopes of the agricultural station, is known to be extremely acidic (Anon, 1975b), with pH values often reaching 4.7 or lower (Harrison and Miller, 1976; Fagan, unpublished data).

The first recorded fertilizer experiment was established in 1961 using three-year-old 1MC 67 trees with Musa cvs. as temporary shade and Gliricidia sp. as permanent shade (Prendergast, 1962a). The major nutrients, nitrogen as ammonium sulphate, phosphorus as triple superphosphate, and potassium as muriate of potash were applied at different rates and in mixtures. After eight years no significant differences between treatments were evident (Anon, 1975a). However, a trend emerged indicating that whereas variable responses to N and P were obtainable, there was consistently no response to K, explained by the high levels of K found in the soil at that site (Harrison and Miller, 1976; Fagan, unpublished data). The low response to N was later shown to be associated with the negative effect of shade on yield of cocoa.

During the earlier years of the cocoa industry in Jamaica, the crop was always grown under permanent shade. The responses of cocoa under shade to fertilizer application had not been specifically examined locally. With the start of the major expansion scheme in 1949, it was considered expedient to investigate such response of rooted cuttings growing under shade (Anon, 1975d). However, such an experiment was not started until 1963, using ICS 95 and ICS 60 growing in a mixed stand at the Orange River Agricultural Station with and without permanent shade. This trial differed from the preceding trial of 1961 mainly in the introduction of a no-shade treatment and in the planting materials used. Yield responses in the no-shade plots started to emerge after the third year, but increases were essentially in response to N, the lower level of which produced better than the higher (Anon, 1975d). Neither phosphate nor potash by themselves gave any significant increases in yield. In the shade environment, no significant response to any of the major nutrients emerged during the first four years. However, favourable interactions between phosphate and the other major nutrients indicated a definite advantage in a mixed fertilizer. Thus N_1P_2 and N_2P_2 were significantly ($P = 0.05$) better than N_1P_1, N_2P_1 and N_2P_0; and P_2K_2 was significantly ($P = 0.01$) better than P_1K_1 and P_2K_1 (Anon, 1975d). In a concurrent observational trial using unreplicated one-acre (0.41 ha) plots each of shaded and unshaded ICS 1 cocoa, the yield of beans in the unshaded plot was 40.5% higher than in the shaded for the eight years 1966-1974 (Anon, 1976).

These results supported to a large extent earlier findings (Murray and Herklots, ibid.) that under increased light intensity, responses to N fertilizers, in particular, increased and there was little response to nutrients under shade.

The effect of liming on fertilizer responses of cocoa in highly acidic soils was tested 1969-1974 in an observational trial in which lime (crushed marl) at different rates was incorporated into the soil. There followed increases in foliar Ca, soil pH and available P, and a 77% increase in yield (Harrison and Miller, ibid.). This marked the end of cocoa nutrition trials in Jamaica for the period reviewed, although no derived recommendations had been forthcoming. However, a nitrogen-fortified NPK fertilizer (16-9-18 plus ammonium sulphate) has been in use on cocoa in Jamaica for some years, at the recommended annual rate of 0.69 kg (1.5 pounds) tree each of 16-9-18 and of ammonium sulphate, in two equal applications. No liming recommendation has been issued and liming of cocoa is not practised.

Pruning experiments

A trial to investigate the effects of different pruning regimes on production was established in 1961, using open-pollinated hybrid seedlings of PA types of cocoa initially growing under shade (Prendergast, 1962b) but without shade after six years (Anon, 1975c). At the 8th year, pruning of trees to leave one jorquette with five fan branches yielded significantly more wet beans ($P = 0.05$) than no-pruning, and black pod disease levels were significantly lower with that regime than in unpruned plots (Anon, 1975c).

Intercropping experiment

An experiment was started in 1972 to determine what gains in productivity and income could be derived from interplanting cocoa with established Malayan Dwarf coconut palms. The experiment also attempted to evaluate different hybrid materials (e.g. PA 150 x ICS 1, PA 150 x ICS 60 and PA 169 x ICS 60) and different planting distances for cocoa in the system (Clemetson, 1975). Yield data recorded after four years indicated that: (a) closer spacing yielded more cocoa as a result of higher plant population densities; (b) hybrids with ICS 60 as a parent were the more productive (Clemetson, 1978; Btarrant, 1978), yielding 20% more cocoa than those with ICS 1 parents (Anon, 1979). Quite apart from the effect of preceding drought, the yield recorded later at six years was quite low, and supported earlier indications that interspecific competition between coconut and cocoa occurred (Anon, 1979). The trend in hybrid productivity was confirmed in a concurrent hybrid seedlings trial at another location, involving ICS 60 and ICS 1 hybrids growing in monoculture cocoa, when hybrids containing ICS 60 female parents yielded 16% more cocoa than those with ICS 1.

Current research trends

Recent agronomic research on cocoa in Jamaica has reflected priorities placed in five main areas of investigation, (i) fertilizer experiments towards an updated recommendation for the industry; (ii) introduction and evaluation of high-yielding blackpod-resistant planting materials; (iii) re-evaluation of cocoa/coconut intercropping; (iv) re-evaluation of cocoa spacing; (v) resuscitation of cocoa propagation by budding.

Fertilizer experiments

With the recognition of an urgent need for an experimentally tested fertilizer recommendation for cocoa in Jamaica, two experiments were initiated in 1983. One was conducted on 20-year-old rooted cuttings (mainly ICS 1, [CS 60 and ICS 95 in a mixed stand) located at Orange River Agricultural Station, and the other on 10-15-year-old hybrids of mixed parentage, located at Montrose in the Richmond Valley of St Mary. Although classed as basically the same soil type (Belfield clay), these two sites differ in soil reaction and physical composition (Orange River: 40.7% sand, 51.1% clay and acidic; Montrose: 66.1% sand, 23.8% clay and neutral to alkaline). One fertilizer treatment was an analytically determined recommendation based on foliar and soil analyses of samples from the sites. This recommendation was compared with available pre-mixed NPK fertilizers (some used in local coconut production), including 16-9-18 + ammonium sulphate (the current recommendation for cocoa). Yield data obtained after the first two years indicated that the best treatment at both sites is the pre-mixed NPK fertilizer 12-10-18 applied at the rate of either 0.45 kg or 0.9 kg (1 or 2 lb.) tree^{-1} annually in two split applications.

New plant introductions

A need for broadening the germplasm base of the Jamaican cocoa industry has been recognized. Importation of hybrid seeds from Trinidad was resumed, and batches of high-yielding and blackpod-resistant TSH selections were received between 1982 and 1984 (Fagan, 1984). These seedlings are being evaluated at a new agricultural station (Montpelier, in St James parish), away from established cocoa-producing areas, as a precautionary measure against any possible introduction of witches' broom disease (*Crinipellis pemiciosa* (Stahel) Singer) which occurs in Trinidad.

Renewal of budding in cocoa propagation

The method of propagation of the moderately blackpod-resistant (locally considered the most resistant) and popular ICS 1 variety is usually by rooted cuttings. However, the supply of such planting material has been persistently limited by various difficulties in its production in Jamaica over the years. The alternative method of propagation by budding was therefore reconsidered after a lapse of interest in this method, and a programme for reviving this method was initiated in 1983. The main rootstock being used is IMC 67 which was chosen for the vigour of its seedlings, but other potential rootstocks such as [CS 60 and PA 150 have been included. With the anticipated success of this programme and subsequent training of personnel in budding techniques, it is envisaged that large quantities of promising varieties of cocoa will be produced for a reviving cocoa industry.

Cocoa/coconut intercropping

An experiment to evaluate the feasibility and desirability of interplanting cocoa with Maypan hybrid seedlings of coconut (now the recommended planting material in Jamaica against Lethal Yellowing disease) was started at Montpelier Agricultural Station in 1984. Besides testing the performance of the two crops, the experiment also attempts to compare the two most popular types of cocoa planting material, rooted cuttings and hybrid seedlings, in the intercropping system. The clone being tested is ICS 1 and the seedlings are ICS 60 x PA 150. These materials are being tested at three spacing distances, 1.8, 2.7 and 3.7 m (6, 9 and 12 ft) along the row, between young coconut seedlings planted at a constant spacing of 6.3 m (21 ft) on a triangular pattern. Plantains (Musa cvs.) were used as temporary shade for the young cocoa plants, with the objective also of providing a readily marketable cash crop in the early years of the cropping system.

References

Anon. (1950a) Cacao: introduction and multiplication of improved strains, *Jamaica Dept Agric. Invest. Bull.* 47 95-96

Anon. (1950b) Cacao: propagation studies, *Jamaica Dept Agric. Invest. Bull.* 47 96-97

Anon. (1951) Cacao: introduction and multiplication of improved strains, *Jamaica Dept Agric. Invest. Bull.* 49 111

Anon. (1964) Cocoa breeding and black pod disease, Discussion Proceedings Jamaica Ministry Agric. Meet., December 16,1964,3 pp

Anon. (1975a) Cacao: fertilizer frequency trial (T. Co.16),*Jamaica Ministry Agric. Invest. Bull.* 63 211-223

Anon. (1975b) Experiment on lime amendments to cocoasoils, *Jamaica Ministry Agric. Invest. Bull.* 63 ix-x

Anon. (1975c) Cacao pruning trial (T. Co.17), *Jamaica Ministry Agric. Invest. Bull.* 63 224-231

Anon. (1975d) Cacao: major nutrient trial (T. Co.15), without and with shade, *Jamaica Ministry Agric. Invest. Bull.* 63 186-210

Anon. (1976) Cacao programme: major nutrient trial, *Jamaica Ministry Agric. Invest. Bull.* 64 234-235

Anon. (1977) Production of cocoa plants in Jamaica, Jamaica Cocoa Industry Board, pamphlet, 3 pp

Anon. (1979) Cacao: cocoa/coconut intercropping -Spring Garden, Portland, *Jamaica Ministry Agric. Invest. Bull.* 1977/78,67 140-141

Barrant, C.I. (1978) Coconut intercropping with cocoa, *Philippine J. Cocoa Studies* 3 29-32

Clemetson, C.A. (1975) Cocoa/coconut interplanting, Spring Garden, *Jamaica Ministry Agric. Invest. Bull.* 65 149-150

Clemetson, C.A. (1978) Cocoa/coconut intercropping, *Jamaica Ministry Agric. Invest. Bull.* 66 125-126

Cunningham, R.K., Smith, R.W. and Hurd, R.G. (1961) A cocoa shade and manurial experiment at the West African Cocoa Research Institute, *Ghana, J. Hort. Sci.* 36 116-125

Dakwa, J.T. (1974) The development of black pod disease (*Phytophthora palmivora*) in Ghana, *Tumalba* 24 367-372

Dakwa, J.T. (1977) Black pod disease and the weather, in: Report of the Cocoa Research Institute, Ghana (197475), pp. 159-161

Dow, D. (1960) Cacao: introduction and multiplication of improved strains, *Jamaica Ministry Agric. Invest. Bull.* 58 77-79

Fagan, H.J. (1984) An assessment of pathological re search on cocoa in Jamaica from 1950 to 1980 and current research priorities, *Trop. Pest Manage.* 30(4) 430-439

Harrison, R.C. and Miller, P.E. (1976) Cocoa fertilizer experiments: lime amendment observation trial, Orange River, *Jamaica Ministry Agric. Invest. Bull.* 64 15-16

Henry, C.E. (1973) Cocoa: varietal susceptibility to *Phytophthora palmivora*, *Jamaica Ministry Agric. In-vest. Bull.* 63 37-39

Henry, C.E. (1974) Cocoa: varietal resistance trials, *Jamaica Ministry Agric. Invest. Bull.* 64 82-83

Leather, RI (1966) Studies on the reaction of some cacao varieties to *Phytophthora palmivora* (Bud.) in Jamaica, *Exp. Agric.* 2 107-112

Murray, D.B. and Herklots, G.A.C. (1955) Climatic requirements of cocoa with particular reference to shade, in: Report of the Cocoa Conference, The Cocoa, Chocolate and Confectionery Alliance, London, Sept. 1955, pp. 17-22

Prendergast, W.N. (1962a) Cocoa: fertilizer frequency trial(T. Co.16), *Jamaica Ministry Agric. Invest. Bull.* 60 55

Prendergast, W.N. (1962b) Cacao pruning trial (T. Co.17), *Jamaica Ministry Agric. Invest. Bull.* 60 51

Reid, D.G. (1981) Variety trial: hybrid seedling crosses,Orange River, *Jamaica Ministry Agric. Invest. Bull.* 68 104

Rocha, H.M. and Machado, A.D. (1972) Faitores ambientais associados corn "podridao parda" do cacaueiro, *Rev. Theobroma* 2(1) 26-34

Spence, J.A. (1961) Black pod disease of cacao: II. A study of the host parasite relations, *Ann. Appl. Biol.* 49 723-734

Topper, B.F. (1953) Variety trial (T. Co.4), *Jamaica Dept Agric. Invest. Bull.* 50 78-80

Topper, B.F. (1957a) A new method of vegetative propagation for cocoa, in: Report of the Cocoa Conference, The Cocoa, Chocolate and Confectionery Alliance, London, 1957, pp. 49-51

Topper, B.F. (1957b) Cacao: introduction and multiplication of improved strains, *Jamaica Ministry Agric. Invest. Bull.* 55 45-46

Topper, B.F. (1964) Cacao: variety trial, *Jamaica Ministry Agric. Invest. Bull.* 62 79-80

Van Hall, C.J.J. (1914) Cocoa, London, Macmillan, p. 139

Vernon, A.J. (1966) The incidence of black pod at Tafo in 1965, in: 2nd Session of the FAO Technical Working Paper on Cocoa Production and Protection, Rome, 1966, Working Paper Ca/66/28, 16 pp

Extracted from Volume 71, Number 4, 1994

The contribution of genotype to cocoa (*Theobroma cacao* L.) flavour

John Clapperton

Mars Confectionery, Dundee Road, Slough SL1 4JX, U.K.

Stephen Yow, Joe Chan and David Lim

BAL Plantations Sdn Bhd, Tawau 91007, Sabah, Malaysia

Rob Lockwood

Commonwealth Development Corporation, One Bessborough Gardens, London SW1V 2JQ, U.K.

Lee Romanczyk and John Hammerstone

M&M/Mars, High Street, Hackettstown, New Jersey 07840, U.S.A.

Received June 1992; revised August 1994

The possibility of genetic effects on cocoa (*Theobroma cacao* L.) flavour was investigated. Consistent differences in flavour attributes, especially cocoa flavour intensity, acidity, sourness, bitterness, and astringency, were found among the West African Amelonado variety (AML), four Upper Amazon clones[Iquitos Mixed Calabacillo 67(IMC67), Nanay 33 (NA33), Parinari 7(PA7), and Scavina 12 (SCA12)1, and a Nicaraguan "Criollo" (UIT1) grown in Sabah, Malaysia. The flavour of UIT1 was distinctly different from the West African standard, being characterized by intense bitterness and astringency associated with caffeine and polyphenols; it also tasted the most acid. These attributes were ameliorated by prolonged storage of the pods before processing the wet beans. The six genotypes differed also in bean size and butter fat content. The differences in flavour were independent of the differences in bean size. The results demonstrated a significant contribution of genotype to flavour in addition to effects of processing.

Keywords: Cocoa; Quality; Flavour; Sensory evaluation; Processing

Traditionally, the market has distinguished between fine grade cocoa produced from Criollo and Trinitario beans (with distinct variants such as Arriba) and bulk cocoa of Amazonian Forastero origin, for which the industrial standard is Ghana, where most of the production is from a uniform lower Amazonian Forastero type known as West African Amelonado. Varieties differ in fermentation requirements, but the relative contribution of the environment, processing techniques, and genotype to flavour development is not understood.

During the last 20 years, there has been an accelerating trend towards the planting of 'modern' varieties selected in breeding programmes. Such varieties have had the greatest impact in Cameroon, Cote divoire, and Malaysia (Kennedy et al., 1987). Most are crosses between a parent derived from Pound's (1938) collection and either an unrelated Upper Amazon or, more commonly, a lower Amazon Forastero or a Criollo/Trinitario type introduced as a clone.

0041-3216/2021/030280-286

The earliest work on the quality of Upper Amazon cocoa was done in Ghana in the early fifties. Manufacturers reported that the flavour was within the West African range, although often weak (MacLean and Wickens, 1951). Subsequently, breeders in Ghana and elsewhere submitted samples of promising new varieties for manufacturers' evaluation, but the results were difficult to interpret. This arose partly because the methods used to process small quantities of wet cocoa gave inconsistent results, often introducing off-flavours, and partly because flavour evaluations were reported on the basis of individual preference rather than on an analysis of flavour attributes. In these circumstances, breeders are unable to select for flavour, and this can be potentially detrimental to both producers and consumers in the long term. Recent investigations in Malaysia, following the study by MacLean and Wickens (1951) on pod ripeness and pod storage, led to an improved understanding of processing techniques (Lewis and Lee, 1986; Duncan et al., 1989). The degree of pod ripeness, storage of pods before breaking, number of turns during fermentation, and speed of drying were shown to influence the development of off-flavours, especially acidity which masks expression of desirable flavours. During that study manufacturers refined their sensory evaluation techniques by dividing flavour into components which were reported separately. Such developments provided an opportunity to re-examine the role of genotype in flavour development. In this study the results of a series of trials are described. These trials were designed to test whether the new processing techniques and improved methods of sensory evaluation would allow identification and analysis of the contribution of genotype to flavour.

Materials and Methods

Selection and cultivation of plant materials

Six genotypes, West African Amelonado (AML), Iquitos Mixed Calabacillo 67 (IMC67), Nanay 33 (NA33), Parinari 7 (PA7), Scavina 12 (SCA12), and UIT1 [an introduced clone with strong morphological affinities to Pound's (1936) Nicaraguan Criollo selections (ICS39, 40, and 60)] were selected for preliminary trials because of their widespread use in cocoa breeding in Malaysia and elsewhere. AML is a seedling population. The other five genotypes are clones.

Fermentation and drying

Experiment 1

Ripe pods from all six genotypes were harvested on the same day and stored for five days before breaking. Spoiled pods and beans were discarded. Fifty kilograms of wet beans were fermented in heaps on trays lined with banana leaves. The wet beans were covered with banana leaves and allowed to ferment for 120 h with a single turn after 48 h. After fermentation, the beans were dried on a platform, using heat from the sun supplemented by an indirect source of heat in prolonged wet weather. Positions on the platform were rotated to ensure that each genotype received the same drying treatment. The entire procedure was replicated four times between October and December 1989.

Experiment 2

The genotype UIT1 alone was used to test the effects of 10 and 15 days pod storage, with each receiving 72 and 120 h fermentation. The trials were replicated three times over a period of six weeks. Extra pods were harvested to allow for expected losses during the longer periods of pod storage. The conditions of fermentation and drying were as described in Experiment 1.

Sample preparation

Coded samples of dried beans from each genotype and treatment of experiments 1 and 2 were sent to the United Kingdom for taste testing. Cocoa liquors and chocolates were prepared according to the recommendation of the Biscuit, Cake, Chocolate and Confectionery Alliance (1980).

Taste testing

Cocoa from each of the four replicates of Experiment 1 were tasted separately as liquors. A hidden reference of West African beans was included in each set before liquor preparation and tasting. The seven liquors (six treatments and the hidden reference) were tasted according to an incomplete block experimental test design in which each liquor was tasted three times. Low intensity red illumination was used to mask colour differences among liquors. The tasting was carried out first by an independent assessor and then by trained panellists from Mars Confectionery who used similar procedures to the one described above, and by trained panellists from other chocolate manufacturers using their own taste procedures for cocoa liquors and chocolates. The 12 liquors from Experiment 2 on Uri with 10 and 15 days pod storage together with a composite sample of UIT1 from Experiment 1 (5 days pod storage and 5 days fermentation) were tasted by the independent assessor according to an incomplete block experimental test design in which each liquor was tasted four times.

For both experiments, intensities of flavour characteristics in Figures 1 and 2 were scored on a continuous 15-cm line scale. Higher scores denoted stronger intensities. Data analysis was by analysis of variance on each flavour attribute.

Cocoa was analysed for several constituents:

Cocoa butter

Cocoa butter contents were estimated by soxhlet extraction (International Office of Cocoa, Chocolate and Sugar Confectionery. 1972).

Caffeine and theobromine

The alkaloids caffeine and theobromine were analysed by the method described by Timbie et al. (1978) using high pressure liquid chromatography (HPLC) and estimated using a diode array detector at 280 nm.

Catechin and epicatechin

The major flavanols, (+)-catechin and (-) -epicatechin were extracted from cocoa as described by Jahal and Collin (1977) and were separated and estimated by HPLC with fluorescence detection.

Procyanidins

Procyanidins (Harbome and Mabry, 1982) were analysed qualitatively using two-dimensional chromatography as described by Jahal and Collin (1977). Fuller details of the procedures for the analyses of caffeine, theobromine, flavanols, and procyanidins are available on request from authors Romanczyk and Hammerstone.

Results

Flavour profiles of the West African reference and the six genotypes from Experiment 1, and the UIT1 cocoa varieties from Experiment 2, from tests carried out by the independent assessor are shown in Figures 1 (a and b) and 2, respectively. More detailed analysis of the scores for cocoa flavour intensity, astringency, acid taste, and (or) sourness are given in Tables, 1, 2, 4, and 6.

Sensory and instrumental analyses of cocoa

Flavour scores, cocoa butter contents, and bean counts from Experiment 1 are listed in Table 1.

The flavour scores were the averages of three tests of each liquor from the four replicate preparations. Five of the genotypes had consistent flavour profiles. The sixth, UIT1, was always the most distinct, but in the fourth replicate its profile was markedly doser to the West African reference than in the other three. To verify that this was a real difference and not the result of the taster becoming conditioned to the flavour and losing discrimination, a further series of tests were carried out in which the four samples of UIT1 and AML from the fourth replicate were compared directly with each other, again with three blind taste tests of each liquor. The results, shown in Table 2, confirmed the changes in the flavour of UIT1 in the fourth replicate. Genotypes AML and NA33 were closest to the West African flavour reference. Genotypes PA7 and SCA12 were slightly more astringent than NA33 and had slightly less cocoa flavour. Genotype IMC67 had significantly less cocoa flavour and was more astringent than the others except UIT1 which was characterized by intense bitterness (Figure lb) and astringency and also had the most acid taste.

Trained panellists from different chocolate manufacturers confirmed the flavour difference indicated by the independent assessor. Most identified AML and NA33 as being closest to the West African flavour. All identified the flavour of UIT1 as the most unlike West African cocoa. Flavour profiles of plain chocolates made from the different genotypes are shown in Table 3. The chocolates were prepared and tasted by Cadbury Ltd, Boumville, U.K. The scores were the combined results from the four preparations of the six genotypes. The chocolates made from UIT1 were significantly stronger in earthy and tobacco flavours and in astringent and metallic tastes. Although the differences in chocolate flavour were not significant, the chocolate flavour from UIT1 was signifi cantly weaker in two of the four preparations.

Genotype NA33 received the highest score for chocolate flavour and had most of the West African flavour character. Cocoa butter contents of PA7, IMC67, and UIT1 were higher than the average, whereas the levels in AML, SCA12, and especially NA33 were below the standard of 56% for West African cocoa.

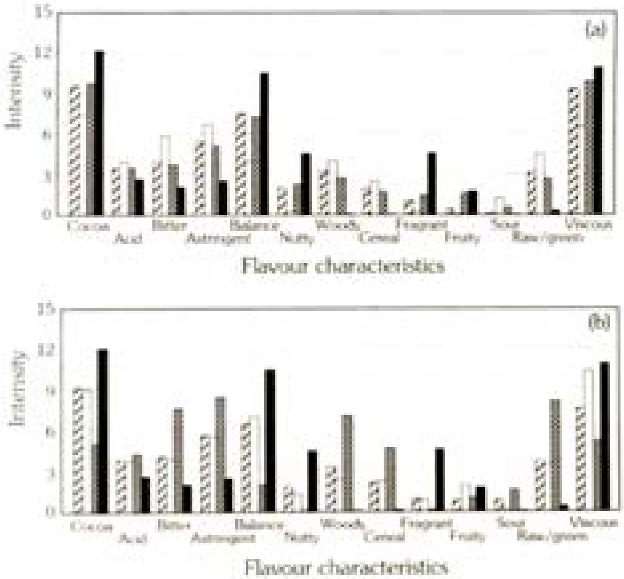


Figure 1 Flavour profiles of cocoa liquors from different genotypes. (a), ▨ AML; ❑ IMC67; ■ NA33; ■ WA ref. (b) ▨ PA7; ❑ SCA12; ■ UIT1; ■ WA ref.

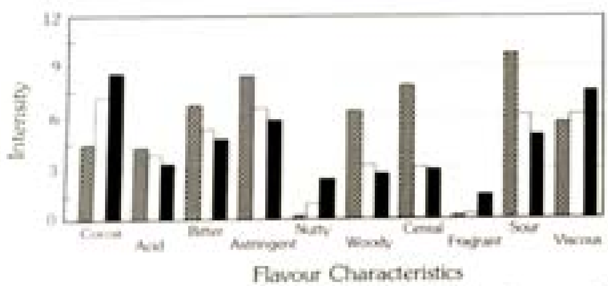


Figure 2 Effects of pod storage time on flavour of UIT1 ■, 5 days; ❑, 10 days; ■, 15 days

Table 1 Flavour scores, fat content of nibs, and bean count for six cocoa genotypes

Genotype	Flavour characteristic Cocoa	Astringent	Acid	Fat content of nibs (%)	Bean count 100-g⁻¹
AML	9.5	5.4	3.4	55.6	95
IMC67	7.3	6.7	3.9	58.2	78
NA33	9.7	5.1	3.4	54.3	104
PA7	9.3	5.7	3.8	58.2	99
SCA12	9.1	5.6	3.7	54.8	124
UIT1	5.1	8.5	4.3	58.1	53
West African reference	12.3	2.4	2.1	56.1	100
SEM	0.4	0.3	0.3	0.4	3

Table 2 Confirmatory sensory evaluation of UIT1

Genotype	Replicate	Flavour characteristic Cocoa	Astringent	Acid
UIT1	1	4.2	9.2	5.4
UIT1	2	4.1	9.0	5.4
UIT1	3	4.1	9.1	5.6
UIT1	4	7.9	6.7	5.5
AML	4	10.2	3.9	3.5

Differences in bean size on flavour

The possibility of a standard roasting procedure leading to under-roasting of larger beans and, thereby. developing only part of the flavours of UIT1 and IMC67 was tested by combining the beans from the first three replicates and selecting samples of AML, IMC67, NA33, and UIT1 with similar bean sizes for liquor preparation and tasting. The differences in flavour among the four genotypes were not significantly altered. The differences in flavour, therefore, are not due to differences in bean size.

Differences in bitterness and astringency levels of alkaloids (caffeine and theobromine which confer bitterness in cocoa) and polyphenols (catechin and epicatechin which confer astringency) in cocoa liquors from the six genotypes are shown in Table 5. The concentration of caffeine in UIT1 could account for its greater bitterness.

The largest differences in catechin, epicatechin, and astringency were between NA33 and UIT1.

Table 3 Flavour profiles of plain chocolates made from six different genotypes

Flavour characteristic	Mean sample scores of four replicate preparations of six genotypes AML	IMC67	NA33	PA7	SCA12	UIT1
Chocolate	4.8	5.1	6.1	5.1	5.4	4.7
Sweet	4.5	5.1	5.5	5.1	5.3	5.3
Acid	1.8	1.8	1.3	2.1	2.4	2.3
Bitter	2.3	2.6	2.1	2.7	2.5	3.2
Astringent*	1.8	3.1	1.6	3.1	2.3	4.3
Metallic*	1.1	1.3	0.7	1.1	0.4	1.7
Brown fruit	2.7	1.8	2.7	2.6	2.8	1.7
Tobacco**	1.1	1.2	0.1	0.4	0.7	1.6
Mouldy*	0.3	1.6	0.2	0.9	0.8	0.7
Musty*	1.1	2.4	0.2	1.1	1.1	1.4
Earthy*	1.3	1.3	0.7	0.7	0.9	1.6
Baggy*	1.3	1.8	0.6	0.7	0.8	1.5

*, Significant difference at P = 0.05 between mean sample scores
**, Significant difference at P = 0.01 between mean sample scores
Scores here are based on a 14-cm line scale

Table 4 Flavour scores for four genotypes after selection to reduce differences in bean size

Genotype	Bean count $100 \cdot g^{-1}$	Flavour characteristic			
		Cocoa	Astringent	Acid	Sour
AML	76	8.1	3.8	2.7	0.6
IMC67	68	6.6	6.5	2.3	3.1
NA33	89	9.1	3.6	2.4	0
UIT1	71	4.6	8.8	3.3	4.3
West African reference	100	9.1	3.6	2.8	0
SEM		0.5	0.4	0.2	0.3

Differences in levels of procyanidins were also detected. The highest concentrations were found in UIT1 and the greatest contrast was between NA33 and UIT1. Astringency generally decreases as the characterizing flavours develop during ripening and maturation.

Effect of pod storage and fermentation time on the flavour of UIT1

Variation in the flavour of UIT1 in Experiment 1 could have been caused by pods maturing at different rates during the five days of post-harvest storage, or by a shorter fermentation requirement because of the Criollo ancestry of UIT1. The effect of different pod storage and fermentation times on flavour characteristics were therefore studied. The flavour characteristic scores are presented in Table 6. They represent averages of eight tests of each liquor from two rounds of tasting. Differences were generally not significant and there were no consistent trends in flavour development between three and five days fermentation. It is unlikely therefore that UIT1 was over-fermented in Experiment 1. Flavour was hanged by storing pods for more than five days before breaking. In Experiment 2, replicates b and c (Table 6), there was further change between 10 and 15 days, with the flavour becoming more like West African as pod storage time increased. Changes in the condition of beans and pulp and the rates of change will vary depending on conditions of temperature and humidity during post-harvest storage, and thus are beyond experimental control. These factors are the most likely reasons for the variable effects of five days pod storage of UIT1 in the first experiment, and the differences among replicates a, b, and c in the second.

Discussion

The controlled procedures and experimental designs used in this study have revealed differences in flavour due to cocoa genotype including AML, NA33, and UIT1, which have been widely used in seed production programmes in Malaysia. The effects reported are from open pollination. Effects of specific pollen donors are currently being investigated.

Cocoa liquors from AML and NA33 were similar to typical West African liquors in colour, flavour, astringency, thickness, and viscosity. Liquors from UIT1 were distinctly different in all of these attributes.

This new information has come from the application of more analytical sensory testing procedures capable of identifying differences in specific attributes, rather than merely to express a preference for overall flavour. Previous assessments of cocoa flavour quality have been on the basis of preference tests of different chocolate manufacturers. While it is perfectly valid to differentiate between samples on the basis of preference, it is erroneous to combine the results of opposing selections. A manufacturer requiring a bitter or drying taste to balance the flavour of another cocoa or confectionery product would probably prefer UIT1 to NA33. Another manufacturer with a different requirement might prefer NA33 to UIT1. It would be misleading to average the preference data and conclude that the cocoa flavours from the two genotypes are equivalent.

Table 5 Scores for bitterness and astringency compared with concentrations of alkaloids and polyphenols in cocoa liquors from six genotypes

Taste and chemical characteristic	Genotype					
	AML	IMC67	NA33	PA7	SCA12	UIT1
Bitterness*	3.9	5.8	3.7	4.1	3.9	7.7
Caffeine ($mg\ g^{-1}$)	1.1	2.1	2.2	1.1	1.8	5.2
Theobromine ($mg\ g^{-1}$)	11.7	10.9	9.1	11.7	10.3	9.5
Astringency*	5.4	6.7	5.1	5.7	5.6	8.5
(+)-Catechin ($mg\ g^{-1}$)	0.6	0.4	0.1	0.5	0.6	1.1
(-)-Epicatechin ($mg\ g^{-1}$)	8.1	6.1	2.7	8.2	5.5	17.7

*Average scores from first experiment

Table 6 Effects of different pod storage and fermentation times on flavour of UIT1

Expt.	Rep.	Date	Pod storage (days)	Fermentation (days)	Flavour characteristic Cocoa	Astringent	Sour
1		Oct-Dec. 1989	5	5	4.5	8.4	9.6
2	a	23.1.90	10	3	7.3	6.3	4.8
2	a	23.1.90	10	5	6.6	7.1	7.3
2	a	28.1.90	15	3	6.8	6.7	6.9
2	a	28.1.90	15	5	7.3	7.1	7.2
2	b	8.2.90	10	3	6.9	6.1	6.1
2	b	8.2.90	10	5	6.8	6.7	6.5
2	b	14.2.90	15	3	10.2	4.1	2.7
2	b	14.2.90	15	5	8.9	5.1	2.8
2	c	24.2.90	10	3	8.3	5.1	3.3
2	c	24.2.90	10	5	8.1	5.6	4.3
2	c	28.2.90	15	3	9.3	5.1	2.6
2	c	28.2.90	15	5	9.6	4.6	2.4
		SEM			0.4	0.4	0.6

Rep. is replicate

Although sensory evaluation must be the primary measure in any flavour study it is desirable to complement the results of sensory evaluation with more objective analytical data. Whereas an instrument can repeatedly provide the same result, the human measuring device in sensory testing may vary because of fatigue and adaptation, but, on the other hand, can reasonably be expected to learn and to develop new perceptions. During the course of the present study, small differences in acid taste observed in the first tests of the different genotypes were translated into more pronounced differences in sourness, which can result either from acetic and lactic acid formed during pulp fermentation, or be due to astringency as in under-ripe fruits. While most people consider Malaysian cocoa to be excessively acidic, some perceive it as bitter and astringent. A number of tasters, including trained and experienced panellists, equated the taste of the present samples of UIT1 with the typical acid taste of Malaysian cocoa. It is possible that part of the sharp flavour of Malaysian cocoa is derived from the choice of planting materials.

In cocoa, astringency can now be related to polyphenols, acid taste to residual organic acids (Duncan et al., 1989), and bitterness to caffeine and theobromine. Apart from differences in these characteristics in different genotypes, there are also differences in colour. The chemistry of these colour differences should be relatively easy to elucidate compared with the exceedingly complex chemistry of cocoa flavour. Cocoa liquors from UIT1 were the palest in colour and were, in this respect, in particular, typical of Southeast Asian rather than West African cocoa liquors. The colour differences most likely relate to differences in polyphenol composition.

The most important practical impact of this study is the information that it provides to planters and plant breeders to produce the cocoa qualities that manufacturers require. The results presented here support and extend the results of earlier unpublished studies on the effects of processing that have shown pod storage to be a major factor affecting cocoa flavour development.

The new evidence is that pod storage will be a major source of variation in any future trials and between different genotypes. A flavour more like the West African standard was achieved from 5 days pod storage of AML and NA33 than from15 days pod storage of UFT1. As large-scale pod storage is problematic on estates in Malaysia there is a strong argument for undertaking genotype evaluation without pod storage. Only genotypes that develop desirable flavour without pod storage would be used for breeding, or selected for large-scale cultivation.

Conclusions

Processing is still a dominant factor affecting cocoa flavour development although planting material is now shown to have a significant effect. The preparation and analytical techniques used make it possible to survey the variation in flavour characteristics of the germplasm on which cocoa breeding is based. The improvements in flavour, colour, and butter fat content could significantly impact on the future development of the cocoa and chocolate industries for the mutual benefit of producers and consumers.

Acknowledgements

This research is published with the permission of the Managing Director of BAL Plantations Sdn Bhd. The authors are grateful to members of taste panels from Cadbury Ltd., Boumville, U.K.; Mars Confectionery, Slough, U.K.; Nestle, York, U.K.; and Eastreco, Singapore.

References

Biscuit, Cake, Chocolate and Confectionery Alliance (1980) Small Scale Preparation of Samples of Chocolate, Bedford Row, London, WCIR 4JH, U.K.

Duncan, R.J.E., Godfrey, G., Yap, T.N., Pettipher, G.L. and Tharumarajah, T. (1989) Improvement of Malaysian cocoa bean flavour by modification of harvesting, fermentation and drying methods — the Sime/Cadbury process, *The Planter* 65, pp. 157-173

Harborne, J.B. and Mabry, T.J. (1982) The Flavanoids: Advances in Research, New York, Chapman and Hill

International Office of Cocoa, Chocolate and Sugar Confectionery (1972) Official Methods of Analyses, 8a E/1972

Jahal, M.A.F. and Collin, H.A. (1977) Polyphenols of mature plant seedlings and tissue cultures of Theobroma cacao, Phytochemistry 16, pp. 1377-1830

Kennedy, A.J., Lockwood, G., Mossu, G., Simmonds, N.W. and Tan, G.Y (1987) Cocoa breeding, past, present and future, *Cocoa Growers' Bull.* 38 5-21

Lewis, J.F. and Lee, M.T. (1986) The influence of harvesting, fermentation and drying on cocoa flavour quality, *The Planter* 62 134-140

MacLean, J.A.R. and Wickens, R. (1951) Small scale fermentation of cocoa, Report of the Cocoa Conference 1951, pp. 116-127

Pound, F.J. (1936) The completion of selection (1935) Fifth Annual Report on Cacao Research (1935),Trinidad. pp. 7-16

Pound, F.J. (1938) Cocoa and Witches-broom Disease. Trinidad, Yuilles Commercial Printerie

Timbie, D.J., Secheist, L. and Keeney, P.G. (1978) Application of high pressure liquid chromatography to the study of variables affecting theobromine and caffeine concentrations of cocoa beans, *J. Food Sci* 43, pp. 560-565

Extracted from Volume 74, Number 1, 1997

The impact of farming systems extension on Caribbean small-farm agriculture: The case of St Kitts and St Vincent

St. Clair P. Barker

Department of Agricultural Economics and Extension, The University of the West Indies, St Augustine, Trinidad and Tobago, W.I.

The impact of agricultural extension programmes over a 10-year period (1986-96) on small farmers in the Organization of Eastern Caribbean States (OECS) was studied. The study showed that adoption was followed by increased total production if action was taken to improve the quality of the frontline worker; intensify his support from Research and Technology generation; use farming systems principles in the conduct of extension work; involve personnel from agencies which support the agricultural sector in extension programming, and establish co-ordinating mechanisms at the district, region (zonal), and national levels. The best results were obtained in an environment of sound policy support and strong co-ordination.

Keywords: Farming systems extension; Small farmers; St Kitts; St Vincent

Generating an improved technology, and informing farmers about it, only creates a potential for change. To realize this potential, farmers require credit, markets for the additional produce, adequate transportation, access roads, and timely information (Berdeque, 1993). The role of extension is to create the conditions which could motivate farmers to change.

Extension strives to bring about changes by stimulating farmers (beneficiaries of extension programmes) to take action to address problems (Barker, 1992). A farmer will not generally undertake farming activities, which he perceives will risk the well-being of his family. or any activity which may damage his relationship with other farmers. Sociocultural forces are very important and may work in a way which prevents a farmer from changing his old practices.

There are opportunities or services other than agricultural information which are required by the entire community. The importance attached to these determines the diligence with which they are sought after, and subsequently influences farmers' adoption behaviour. They could be social, cultural, economic, political, climatic and (or) environmental, educational, communicative, or industrial (Leagans, 1961, 1985). They can lead to positive or negative outcomes, depending on their impact on farmers' lives. If the effects of the elements lead to a reduction or cessation in income they are said to have a negative effect. Thus, any element or set of elements which works against and neutralizes the negative effect is considered to be supportive because it creates opportunity for expanded activity and income generation.

When these support services are absent or deficient, the farmer makes the necessary adjustment to minimize any negative impact on his well-being. His response is manifested through a particular kind of behaviour.

Supportive policy can provide infrastructure (roads and water for irrigation) and (or) reduce tax on agricultural inputs, farm machinery, and equipment thus reducing the financial requirement by the farmer to initiate a farm project and probably allow the local farmers to produce at lower cost per unit of produce. However, the single most frequently mentioned constraint to the development of the small-farm business in the Caribbean is marketing (Barker et al. 1986; Campbell, 1986, Dolly and Young, 1990). Generally, marketing personnel are not invited to participate in extension programming.

Traditionally, participation in extension programmes includes the generators of technology. the disseminators, and the end users (Cohen and Uphoff, 1980: Cernea et al., 1985: Pickering, 1989: Cuyno, 1988). Correspondingly, the traditional extension linkages emphasized a triangular relationship between

0041-3216/2021/030287-293

research. extension, and farmer. However, marketing agents, input suppliers, and credit institutions are also important (Mosher, 1969; Woods, 1988; Kaimowitz, 1990; Thomas, 1993). Their inclusion can benefit and support farm planning and enhance training and programme implementation and, according to Barker (1992), are called Support Systems. In spite of this demonstrated effect, extension programmes, for many reasons, are not making the expected significant impact.

The Problem

The majority of farms in the English-speaking Caribbean are less than 5 ha in size. Small-scale farming consists mainly of multiple-cropping systems, and research on this type of farming is still very new. Not only is technological information lacking for these small-scale farmers. but the socioeconomic and sociocultural factors are generally not well analysed prior to the development of programmes of change.

Frontline extension workers (FEWs) who have a diploma or certificate in general agricultural production and are in direct contact with the farmer are given the responsiblity for bringing about positive change in the farmers' standard of living. Given these problems and the limited scope of the FEW, very little impact has been achieved (Lightfoot and Noble, 1993).

Henderson (1970) indicated that the number of roles which the FEW is expected to perform leads to conflict. Similarly, the Caribbean Agricultural Extension Project (CAEP, 1980) found that FEWs had educational responsibilities as well as regulatory functions which very often did not foster good extension-farmer relationships.

Administrators and leaders of extension in the English-speaking Caribbean have tried many extension approaches in an attempt to achieve greater impact (Barker, 1994a), but some problems are rooted in the policy decisions, budgetary allocations, disbursement strategies. infrastructure, transportation, and other factors which are related to work conditions and motivation (Arnon, 1981, Seepersad, 1986).

A review of extension programmes indicates that they are not necessarily having the expected impact on the farmer's standard of living. There is some indication that there has been some progress where the FEW is supported by better trained agriculturist(s). Many territories, however, lack university-trained persons to work in the frontline and, where there are such graduates, they are most frequently in management positions and are very far removed from the field, with very little contact with the farmer. Thus, extension appears to have a low impact on farmers lives. There is no appreciable reduction in the Regional Food Import Bill which now stands in excess of E.C. $3 billion dollars (OECS Economic Reports 1986-1994; U.S. $1.00 E.C. $2.70).

The ineffectiveness of the agricultural sector persists in spite of the fact that there are national policies to pursue diversification, with agricultural extension leading in that effort. The agricultural successes achieved through the efforts of extension over the last decade are few. Extension programmes, which were supposed to bring about economic change in the beneficiaries, continue to have very little impact, or are failing in absolute terms, in spite of the fact that most of the components (available technology, input supply, agricultural services, credit, and marketing) necessary for the conduct of an effective agricultural programme are present in the farming community (Barker and Bishop, 1992). There is no co-ordination of the efforts or the resources which are supposed to be used to the benefit of the small farmer. Not only is the co-ordination function unattended by extension, but the work of the extension staff lacks direction and purpose. Their work is generally unfocussed and unsystematic (Henderson and Patton, 1985).

Objectives of the Study

The objectives of the study were (i) to identify and analyse recent agricultural extension programme initiatives, (ii) to make an assessment of the impact extension programmes were having on increasing total national agricultural production, and (iii) to make recommendations for the conduct of future extension programmes.

Methodolody

The research methodology involved the use of a survey, the testing of specific extension efforts on a group of farmers in Antigua (the control), and the monitoring of extension programmes over a 10-year period in St Kitts - Nevis, and St Vincent and the Grenadines (SVG).

Grambling and Freudenburg (1992) suggest that programme impact is best observed over the long run. This study was conducted from a period 1986 to 1996 and was facilitated through the CAEP Work Programme and later the Faculty of Agriculture's Research Fund of The University of the West Indies (U.W.I.). In SVG, an evaluation was done of the Diversification Programme which included land reform (Barker and Bishop, 1992; Barker, 1994b). In Antigua, an evaluation was conducted on the fruits and vegetable production programme. In St Kitts - Nevis, the vegetable production programme was evaluated.

Research Methods

The support of at least one Agronomist and three Extensionists at each research site was secured. Rapid Reconnaissance Surveys (RRS) were carried out, and on-farm interviews were conducted with farmers and their representatives. Focus group meetings, consultation meetings. and interviews using structured questionnaires were conducted with farmers, extension officers. and agricultural administrators and (or) policy makers. In-depth consultations were carried out with researchers and agricultural specialists in the plant, livestock, and soils disciplines. Similar interviews were carried out with personnel in credit, marketing, and input supply agencies or institutions as well as other non-governmental organizations (NGOs) working in the research area.

Based on the findings, efforts were made to collaborate with the Ministries of Agriculture personnel in developing district and national extension programmes. Training was provided for extension staff at the local and regional levels. The researcher and other U.W.I.-CAEP staff became an integral part of the programme implementation thrust. The programme implementation utilized farming systems principles.

In Antigua, a multidisciplinary team was responsible for all extension activities at the frontline. In St Kitts, similar teams were developed along commodity lines and included marketing and input supply representatives. In St Vincent, the programme was implemented by the individual district extension worker and did not follow farming systems extension (FSE) principles, but that of a traditional approach.

Initially, 30 farmers were used to demonstrate the extension process to extension staff and to demonstrate to farmers that they can benefit from their collaboration.

Farmers were taught farm business management, and co-operating extension officers received intense training from the U.W.I.-CAEP Extension and Farm Management specialists. Baseline data were collected on each farm prior to the interventions.

Based on the evaluations made at the end of the research activity and (or) intervention, the CAEP was extended to include all farmers in each island. It officially came to an end in 1989 and the continuing activities were incorporated into the Agricultural Research Extension Project (AREP). The monitoring of the impact of the extension programmes continued for six years after the end of U.W.I.-CAEP initiatives.

Findings of the Field Survey and Discussion

The interventions made by U.W.I. and the Caribbean Agriculture Research and Development Institute (CARDI) tried to remove some of the constraints to successful small-farmers' agricultural production with a hope of fostering a better quality of life for them. These efforts were made through the CARDI Farming System Research and Development (FSR/D) project; the CAEP and the AREP were funded by the United States Agency for International Development (US-AID), CAEP (Evaluation Report, 1989), and the AREP (Evaluation Report, 1994). One of the objectives was to use farming systems principles to enhance both the relevance of research and at the same time reduce the time taken for adoption of technologies. As a result, the U.W.I.-CAEP, in collaboration with the Ministry of Agriculture, field-tested the farm and home management extension (FHME) approach (Barker, 1994a), and, more recently, implementation strategies such as the task force (TF; Bailey et al., 1992) and joint focus programming (JFP; Campbell, 1992) have been used in the implementation phase. These efforts used farming systems concepts. The FHME and the TF represent the approaches which have demonstrated a high degree of impact among small producers of roots, tubers, and vegetables in Montserrat, St Kitts and Nevis, and Antigua.

Throughout the implementation of the CAEP. beneficiaries kept farm records which were analysed by a team of external evaluators. They also conducted interviews with the beneficiaries, extension specialists, researchers, farm management specialists, representatives of other collaborating agencies (e.g.. commodity associations and NGOs), and administrators of agriculture. Based on these findings, it was concluded that the extension activities implemented through the CAEP have had an impact on both extension officers and farmers. Some of the more important results were the following:

1. Extension officers in the demonstration districts were much more knowledgeable about farm management and ways of working with farmers that will enhance their well-being.
2. Target farm families benefitted from the extension effort in the demonstration districts as evidenced by the fact that target farm families had increased enterprise-re-ceipts, farm and family earnings, and net worth in 1987 compared with 1986; had adopted a variety of new production and management practices; could offer their farms for use as demonstration farms to show the effects of improved practices; had greater knowledge of production and marketing; had improved attitudes toward farming and extension; made changes in enterprises that resulted in more diversification, more vegetable production, and production more suited to market needs; and contributed to meeting seasonal deficiencies and thereby helped meet some of the nutritional needs of their families and the region (CAEP Evaluation 2, 1989).

An analysis of the production data from a sample of OECS states indicated a decline in production in countries such as SVG where a traditional extension approach was pursued, and where the university graduates who supervised the extension zones had little farmer contact. In St Kitts - Nevis where the FSR-E approach was followed and where the university graduates formed part of the teams which worked directly with farmers, there was an increase in production (by volume) of approximately 100% over the 1986 level of production (Tables 1, 2, and 3).

Generally speaking, there was a tendency for the extension systems in Antigua to revert to the traditional method when the CAEP ended (i.e., no major focus; one-on-one approach with minimal meaningful farmer involvement in planning, implementation, monitoring, and evaluation; a top-down style of management and programming;

Table 1 Annual yield of some selected commodities for St Vincent and the Grenadines (‘000 kg)

Commodity	Year								
	1986	1987	1988	1989	1990	1991	1992	1993	1994
Cabbage	756.6	107.5	118.2	157.3	195.5	171.1	195.9	371.0	76.5
Carrot	—	—	—	80.5	54.8	49.5	16.9	13.4	55.8
Hot pepper	108.4	579.3	97.9	79.0	61.0	67.1	61.0	4.0	5.2
Sweet pepper	21.5	18.3	19.2	20.1	18.0	16.5	18.0	2.5	2.5
Tomato	98.6	47.0	59.2	124.1	63.6	55.8	63.6	125.9	125.9
Total	985.1	752.1	294.5	461.0	392.9	360.0	355.4	516.8	265.9

Source: Agricultural Planning Unit of the Ministry of Agriculture, Kingstown, St Vincent and the Grenadines

Table 2 Annual yield of some selected commodities for St Kitts (‘000 kg)

Commodity	Year								
	1986	1987	1988	1989	1990	1991	1992	1993	1994
Cabbage	22.7	18.1	45.4	56.7	27.2	39.5	102.1	73.0	114.0
Carrot	22.7	34.0	45.4	59.4	56.7	45.4	66.0	38.7	52.0
Onion	2.3	2.3	4.5	4.5	4.5	13.6	27.8	39.9	115.0
Tomato	45.4	54.4	68.0	77.1	68.0	89.4	106.3	109.6	100.0
Sweet pepper	11.8	11.8	9.1	22.7	11.3	9.1	8.3	10.7	23.0
Watermelon	18.1	34.0	36.6	31.8	45.4	55.0	57.0	68.0	73.0
Total	123.0	154.6	209.0	252.2	213.1	252.0	367.5	339.9	477.0

Source: Notes from Dr Jerome Thomas, Ministry of Agriculture, Basseterre, St Kitts and Nevis

Table 3 Annual yield of some commodities for Antigua and Barbuda (‘000 kg)

	Year						
Commodity	1989	1990	1991	1992	1993	1994	1995
Tomato	161.6	188.4	114.9	173.9	361.9	168.7	143.2
Carrot	153.7	269.2	106.1	175.2	249.8	203.5	130.2
Onion	119.3	296.6	95.3	276.2	190.4	214.7	180.8
Cabbage	32.0	54.7	37.5	29.1	94.1	108.1	96.4
Sweet pepper	18.8	95.0	28.7	40.2	44.3	14.6	12.9
Total	485.4	903.9	382.5	694.6	940.5	709.6	563.5

Source: Notes from Mrs M. Forde, Ministry of Agriculture, St John's, Antigua and Barbuda

emphasis on services rather than on teaching and education; and no real effort to involve personnel from NGOs. credit, marketing, and input supply agencies, or academic institutions.

In Antigua and SVG, a number of agencies which had a mandate to support the agricultural sector could be identified, but they had no meaningful relationship with extension and with each other, and their efforts were not effectively reaching the small farmer. In SVG, in particular, policy support. technology generation, credit, marketing, academic and other public institutions, land reform, input suppliers, agricul-tural services, farmer organizations, NGOs, and community services were all present but their efforts were not co-ordinated and they did not contribute significantly to the national objective to have more productive farmers.

A number of crops were identified, researched, and developed to a point where they were ready for full commercialization in SVG, but the supporting elements, including extension, did not allow such to happen. Actually, some initiatives such as onion and passion fruit production showed no increase in area planted, and total production was still negligible (i.e. no production data was generated) after 10 years of inclusion in the extension programmes. Also, in 1995, the potential onion growers and the Ministry of Agriculture and the St Vincent Marketing Corporation (the main purchaser) could not agree on a working relationship to enable commercial production to take place. Not only has onion production not increased, but other vegetable crops were actually declining compared to the 1986 levels (Table 1).

On the other hand, St Kitts - Nevis had a number of linkages with the marketing, credit, input supply, technology generation, policy, trade, land development, and other private-sector agencies. The entire implementation process included all the sectors which could contribute to the successful outcome. As a consequence the total agricultural output in fruits, roots. and vegetables was on the increase (Table 2).

Antigua was used as the control. The FHME approach was used to work on a limited number of commodities which included toma-toes, cabbage. and carrot. The increases in the production levels were as a result of specific intense extension efforts supported by research. Greatest impact was achieved in tomato production, as indicated in Table 3. The same was evidenced in cabbage production, but the market demand limited the extent to which the crop could be expanded, while the drought of 1994 and the tropical storms of 1995 significantly reduced the production of tomatoes.

It must be argued that the extension team in Antigua has been able to demonstrate impact in vegetable production. This impact was achieved without the help of the Private Sector (marketing, credit, input suppliers, and providers of agricultural services such as engineering). But these levels were not sustained. Much more could be done if all activities directed to help the farmer were co-ordinated not unlike that in St Kitts - Nevis (Table 3).

Mechanisms were put in place to ensure that there was support from the agricultural specialists resident in the islands (St Kitts - Nevis and Antigua). This mechanism took the form of production co-ordination committees (PCC).

There was no such mechanism in SVG. In Antigua and Barbuda the life of the Production Coordination Unit was short-lived. As a result, linkages between extension, research, and the private sector were tenuous. Production gains on both islands (Antigua and SVG) were very erratic and sustainability in agricultural production was low. In Antigua. high levels of onion production could not be maintained because of the lack of support from the Central Marketing Corporation (CMC) and other private-sector agencies. This resulted in the loss of large quantities of the produce at the farm level due to the limited quantities bought by the CMC and a lack of proper storage. This experience led to a reduction in levels of production by the individual farmers.

Conclusion

Policy-makers must ensure that the best trained, most proficient officers work with farmers. Even with improved manpower capability in the frontline, agriculture is not likely to bring about the changes which the policy-makers anticipate unless efforts are made to provide adequate working conditions, transportation, and supporting services to ensure the successful conduct of the extension programmes.

There is need to put in place mechanisms which would co-ordinate extension programmes at the frontline or district level and the functions of all collaborating agencies. A systems perspective should be observed in working with farmers as well as in managing and supporting extension programmes at the national, regional, and district levels.

A systems approach to the conduct of agri-cultural extension programmes provides the Third World's small farmers with the best opportunity for survival. But policy-makers must be strong enough to insist on the placement of better trained officers in the frontline and to insist on participation of those who can influence programme outcome at all levels.

References

Arnon, I. (1981) Modernization of Agriculture in Developing Countries. Resources. Potentials and Problems, Chichester, New York. John Wiley and Sons, 565 pp.

AREP (Agricultural Research Extension Project) (1994) An External Evaluation Report, Department of Agricultural Extension, Faculty of Agriculture, U.W.I., St. Augustine, Trinidad and Tobago, W.I.

Axin, G.H. and Thorat, S. (1972) Modernizing World Agriculture. A Comparative Study of Ex-tension Education, New York, Praeger Press

Bailey, E., Ameen, I., Ross, J., Hosein, A. and Clarke, B. (1992) An Integrated Approach to the Transfer of Agricultural Technology in the OECS, Report of the 8th General Meeting of the Regional Agricultural Research and Extension Co-ordination Committee, Castries, St. Lucia, Depart-ment of Agricultural Extension, UWI/CARDI, St Augustine, Trinidad and Tobago. W.I.

Barker, St. C.P. (1992) Conceptualizing the Research/ Extension Linkage for Agricultural Development in the Caribbean, Paper presented at the 8th General Meeting of the Regional Agricultural Research and Extension Coordination Committee, Castries, St Lucia. Department of Agricultural Extension, U.W.I., St Augustine, Trinidad and Tobago, W.I.

Barker, St. C.P. (1994a) Farm and home management extension: A new approach in agricultural extension, *Trop. Agric. (Trinidad)* 71 (4) 313319

Barker, St. C.P. (1994b) An Evaluation of the Agricultural Diversification Programme in St Vincent, Ministry of Agriculture. Kingstown, St Vincent and the Grenadines, W.I.

Barker, St. C. and Bishop, C. (1992) An Evaluation of the Land Reform Programme with Emphasis on Rabacca Farms, Ministry of Agriculture. Kingstown, St Vincent and the Grenadines, W.I.

Barker, St. C.P., Gomes, P.I. and Rankine, L.B. (eds) (1986) Farming Systems of North Antigua: Report of a Rapid Reconnaissance Survey, Department of Agricultural Extension, U.W.I., St Augustine, Trinidad and Tobago, W.I.

Berdeque', J.A. (1993) Challenges of Farming Systems Research and Extension, *J. Farming Syst. Res-Ext.* 4 (1) 1-9

CAEP (Caribbean Agricultural Extension Project)

(1980-1981) Institution Analyses of St Vincent, St Lucia, Dominica, Antigua and St Kitts-Nevis, Department of Agricultural Extension, U.W.I., St Augustine, Trinidad and Tobago, W.I.

CAEP (Caribbean Agricultural Extension Project) (1989) An External Evaluation Report, Department of Agricultural Extension, U.W.1., St Augustine, Trinidad and Tobago, W.I.

Campbell, D.A. (ed.) (1986) Farming Systems in the Eastern District of Grenada, Report of a Rapid Reconnaissance Survey, Department of Agricultural Extension, U.W.I., St Augustine, Trinidad and Tobago, W.I.

Campbell, D.A. (1992) Joint Focus Programming, Department of Agricultural Extension, U.W.I., St. Augustine, Trinidad and Tobago, W.I. and the Grenadines

Cemea, M.M., Coulter, J.K. and Russel, F.A. (eds.) (1985). Research-Extension-Farmer, A Two Way Continuum for Agricultural Development, The World Bank, Washington, D.C., pp. 1-12

Cohen, J. and Uphoff, N. (1980) Participation's place in rural development: Seeking clarity through specificity, *World Development 8* (3) 213-236

Cuyno, R.V. (1988) Research system and research utilization: How to reach to end-users, *J. Ext. Syst. 4* (2) 63-74

Dolly, D. and Young, G. (eds) (1990) Report of a Rapid Reconnaissance Survey in Country Caroni, Department of Agricultural Extension, U.W.I., St Augustine, Trinidad and Tobago, W.I., 253 pp.

Grambling, R. and Freudenburg, W. (1992) Opportunity-Threat, Development for Social Impact Assessment, *Rural Sociol.* 57 (2) 216-234

Henderson, T.H. (1970) Conflicts in the Role of the Extension Officer in the Windward Islands, Department of Agricultural Extension, U.W.I., Trinidad and Tobago, W.I., 17 pp.

Henderson, T.H and Patton. M.Q. (1985) Agricul-tural extension for rural transformation: The C.A.E.P Model, in: Rural Development in the Caribbean (ed. Gomes, P.I.), London, C. Hurst and Company, pp. 194-211

Kaimowitz, D. (1990) Making the Link Agricultural Research and Technology Transfer in Developing Countries, International Service for National Agricultural Research (ISNAR), Boulder. San Francisco, and London, West View Press, 278 pp.

Leagans, J.P. (1961) Extension Education in Community Development (ed. Kamath, M.C.), Directorate of Food and Agriculture. New Delhi, Glasgow Printing Company, pp. 1-26

Leagans, J.P. (1985) Adoption of technology by small farmers: A model for strategy builders, *J. Ext. Syst*. 1 (1) 1-21

Lightfoot, C. and Noble, R. (1993) A participatory experiment in sustainable agriculture, *J. Farming Syst. Res.-Ext.* 4 (1) 11-34

Mosher, T.A. (1969) Creating a Progressive Rural Structure, Agricultural Development Council Incor-porated, U.S.A., Sowers Printing Co., 172 pp.

OECS (1986-1994) Annual Economic Reports, OECS Office, St. John's, Antigua and Barbuda, W.I.

Pickering, D.C. (1989) A two way continuum for agricultural and rural development, *J. Ext. Syst.* 5 (1) 1-12

Seepersad, J. (1986) Background factors related to the job satisfaction of extension field staff in Trinidad, *Trop. Agric. (Trinidad)* 63 (2) 149154

Thomas, E. (1993) Partners in agricultural technology: Linking research and technology transfer to serve farmers, ISNAR Res. Rep. No. 1, The Hague

Woods, J.L. (1988) Making rural development projects more effective: A Management Systems Approach, *J. Ext. Syst.* 4 (2) 3-28

Extracted from Volume 79, Number 4, 2002

Small farmers' production constraints and implications for agricultural diversification in the Caribbean

St Clair Barker

Department of Agricultural Economics and Extension, Faculty of Agriculture and Natural Sciences
The University of the West Indies, St Augustine, Republic of Trinidad and Tobago

A long-term study was conducted between 1981 and 2001 in St Vincent, West Indies, and other short-term studies were conducted in the 1990s in the islands of Antigua, Barbados, and Trinidad, West Indies, to determine the major constraints to agricultural production and the influence of these constraints on the sustainability of agricultural diversification programmes in these islands. The results indicated that many of the constraints were common and included marketing, labour, pests and diseases, and praedial larceny. Agricultural information gathering was not a major problem and the main sources of information were the agricultural officers, the media, and other farmers. Agricultural diversification was not successful because it varied with the financial viability of the crops and how well the programmes were advertised and disseminated among the farmers.

Keywords: Diffusion; Innovation: Adoption: Diversification; Participation; Motivation

The agricultural sector of the English-speaking Caribbean has its origins in the plantation and estate agricultural systems (Smith, 1974). The reduction of financial returns from the production and marketing of traditional agricultural products such as arrowroot starch, cane sugar, cacao beans, and most recently, bananas, led individual countries in the Caribbean to pursue a policy of agricultural diversification in an effort to reduce economic risks, and if possible, increase export earnings as well as save foreign exchange (Persaud, 1969; Demas, 1987).

Henderson (1990) postulated that agricultural diversification may not be as successful as planned, because farmers are not motivated to adopt those innovations which the progammes offer. Nevertheless, it could be argued that diffusion or communication of information on a specific new technology is a prerequisite to its adoption. The Caribbean Agricultural Extension Project (CAEP) identified a number of problems which included information facilities and technical information. The CAEP also developed programmes and strategies that would reduce the negative impact on the diversification process.

Agricultural diversification in the Caribbean has been very difficult to successfully develop because the small-island states have had to compete with larger states (Gumbs, 1998). Inefficient production systems, low level of technologies, poor or deficient transportation, market restrictions including non-tariff barriers even when trade agreements exist, and the economy-of-scale disadvantages of small states plague the diversification efforts (Gumbs, 1998). More specifically, the Ministry of Agriculture (MOA) in St Vincent in keeping with the Government's policies as outlined in the St Vincent National Agricultural Policy (1975), the Policy Paper (1986), and the Five-year Programme (1993), embarked on an ongoing campaign to promote the diversification of the agricultural sector. Governmental support to the diversification thrust included the expansion of the feeder-road programme, the establishment of marketing depots within the farming communities, the expansion of the facilities, and the scope of the St Vincent Marketing Corporation (SVMC). The investment on the part of the Government and the importation of recommended agricultural inputs amounted to millions of dollars which was a significant part of the national agricultural budget.

Marketing was facilitated through the SVMC and credit was offered on a 'crop-lien' basis (specifically to small farmers) through the Agricultural Development

0041-3216/2021/030294-301

Bank (later the Development Corporation). More recently, a number of plots of farmland were made available to small farmers through the Agricultural Rehabilitation and Development Project and the Land Reform Programme (John, 1996).

In spite of the Government's support, the island's agriculture has not diversified more than it was 20 years ago when banana, arrowroot, sweetpotato, eddo, yam, nutmeg, coconut, and small ruminants contributed significantly to the total agricultural contribution to Gross Domestic Product (GDP) (Statistical Trade Reports, 1980-2000). Export agriculture and earnings are still declining and there is still an economic dependence on banana. At its peak, as many as 6500 small farmers participated in the production campaign and sold produce to the SVMC. and most domestic and export quotas were met. For a while, the combined export of food crops to regional ports (mainly Barbados and Trinidad) contributed as much as banana did to the agricultural economy. Since then, export has been falling progressively. This decline has taken place although a number of the supporting factors of production were made available to the small farmers, and in an environment where unemployment ranges from 20-40% and the demand for food in the region is increasing as reflected in the regional food-import bill (OECS Economic Reports, 1980-1998).

The decline of carrot production and other food crops (sweetpotato, eddo, yam, and plan-tain) affected life at the village or district level, as farmers experienced a loss of income, a decline in economic activity, and at the national level, a loss of foreign exchange earnings.

Given the local conditions including available technology, suitable climatic conditions, inputs availability, guaranteed markets, and some policy support (includng extension services), export efforts failed. Other attempts to commercialize other new crops have not been very successful and in some cases, they are failing as well. The factors (social, economic, political, and physical) constraining successful production of carrots and other vegetables and food crops by the majority of small farmers have not been documented.

The failure to bring about significant change in the agricultural sector in response to trade liberalization and the removal of preferential markets is common to a number of Caribbean countries [including the Organization of Eastern Caribbean States (OECS), Trinidad and Tobago, and Barbados].

In 1981, a study was conducted among vegetable and root crop farmers in St Vincent to determine their level of knowledge of vegetable and root crop farming, their adoption of technology existing for these crops, their sources of information, and the degree to which they had adopted diversification efforts. Diversification here means a change of the crop base within the farming systems or a change in the number of crop species. In 1994-1995, a follow-up study was conducted with the aim of determining whether the diversification process had continued and whether it had become profitable for the farmers to diversify their cropping base. In 2001, a further follow-up study was conducted to determine if there was any change. In 1997-2000, a similar type study was conducted in Antigua with the aim of determining whether there were any similarities in the findings between Antigua and St Vincent. The study was extended to include Barbados in 1998 and Trinidad in 2001. The methodology for each island is included.

Agricultural Diversification Features of the Islands and the Study Methods Used

St Vincent

St Vincent has inherited structural rigidities that constrain rapid transformation from one enterprise to another (Robertson, 2002). Thus, the agricultural diversification effort in this island will of necessity be a very slow process. The diversification process was mainly instituted through the need to diversify out of banana production which was the mainstay of the St Vincent economy. However, although there was still a marked focus on banana production, many farmers were being increasingly encouraged to diversify their banana production and include vegetables and root crops as part of their production strategies.

In 1981, a field survey was conducted among a sample of 150 vegetable small farmers. Based on the findings of the 1981 survey, and the recommendations made, a medium- to long-term programme was developed with inputs from both farmers and extension officers with the aim of alleviating the problems. Farmer training schemes included method and result demonstrations which were conducted on both Government agricultural stations and on farmers' holdings.

In 1994-1995, a follow-up study was conducted with the aim of assessing the impact of the programme of interventions. The methods used to gather the information consisted of a Rapid Rural Appraisal (RRA). consultations with farmers, mass meetings. and a survey which was conducted via the use of questionnaires. Thirty-two independent variables were assessed. Approximately 400 farmers participated and contributed to the RRA and mass meetings, while 106 farmers were interviewed and their farms visited.

In 2001, a further follow-up study was conducted, whereby 170 small farmers were assessed to determine if any further changes were made in the farmers' diversification efforts.

Antigua

The contribution of agriculture to the GDP in Antigua has been decreasing over the last 25 years (Kentish, 2002). Although it had initially made the highest contribution to GDP, in 1980 its contribution was reduced to 12% and by 1996 it had further declined to 4.5% (Kentish, 2002). Employment in agriculture is about 4% of the nation's labour force, and agriculture is generally characterized by small-scale part-time farmers (Kentish, 2002). The main agricultural crops formerly produced in Antigua were sugar cane and sea island cotton. However, as a result of the reduced quotas for sugar on the world market, there was an urgent need to diversify out of sugar cane production. Antigua has also rapidly increased its tourism industry, with the concomitant increased demand for other agricultural products. In 1997, an extension campaign was launched among small-scale crop farmers, while in 2000, an extension survey was conducted among 86 farmers in Antigua. The process encouraged voluntary participation. A strategy was developed to guide the participating farmers to identify their farm-based problems and to prioritize those for immediate inclusion into the extension programme. A major focus of the effort was to remove the negative effect of as many problems as possible, which constrained the farmers' production efforts. Thus, personnel from the disciplines of agronomy, engineering, irrigation technology, pest management, marketing credit, and gender affairs were involved in the effort.

Meetings were held with farmers on a monthly basis for 48 months (1996-1999) at which technical and farm-related issues were discussed. An annual farmer-training programme was carried out over a 12-week period for three consecutive years (1997-1999) and farmers throughout the island were invited to attend sessions of their choice. Farm demonstrations were mounted on farmers' holdings and on District Agricultural Stations to reveal the latest techniques available in onion, tomato, cabbage, and pepper production. Farmers were taught management practices of pests and diseases such as the diamond back moth in cabbage and the Gemini virus complex in tomato. An evaluation of the broad-based extension programme was conducted among a sample (86) of small farmers in order to assess the degree to which the programme influenced their decision-making about crop production.

Barbados

The Barbados economy in additional to its agricultural contribution to GDP, also relied on the tourism sector. The agricultural contribution has mainly been the production of sugar cane. A Rapid Rural Appraisal was conducted in 1998 among a stratified sample of 214 farmers. The objective of this appraisal was to determine the existing constraints to small-scale farming, and if possible, the similarities and disparities that may exist among small-scale farming in Barbados versus those of St Vincent.

Trinidad

Although Trinidad and Tobago did not follow specific diversification programmes in the 1980s and the 1990s, the whole concept of agricultural development was articulated in almost all of the policy goals of the Ministry of Agriculture (Harry, 2002). There was one exception, the state-owned company, Caroni (1975) Ltd. There was a deliberate agricultural diversification programme in effect from the 1980s onwards. The current Sector Policy on Food Production (2002-2005) outlines several policy goals related to the diversification process (Harry, 2002). In Trinidad and Tobago, the overall aim of diversification is to increase foreign exchange earnings, improve local food security, maintain stability and sustainability in the supply of agricultural commodities, and increase the income of farmers (Harry, 2002).

In 2001, a study was conducted with the objectives of identifying the constraints to crop rehabilitation and expansion and to identify similarities and disparities to the problems compared to those of St Vincent, Antigua, and Barbados. For this appraisal, a total of 240 tree crop farmers were utilized.

Statistical analysis

Simple random samples as well as stratified random sampling (Seltiz, 1959; Blalock, 1960; Moser, 1969; Freund, 1973) were used at different periods in the conduct of the study. Where appropriate, chi-square analyses were used to test the relationship between the dependent and independent variables, while descriptive data were expressed as percentages of the number of cases studied.

Results

St Vincent

In the Caribbean region, the system of crop farming practised, in most cases, is mixed cropping. In St Vincent, in particular, farmers classify themselves within a particular farming system based on the profitability of that crop and not on the actual land size devoted to the crop. Thus, although structural rigidities exist which make it difficult to move from one farming enterprise to another, because the small farmers plant a mixture• of the crops outlined in Table 1 at the same time, they reclassify their farming system at different times based on the profitability of an existing crop. As shown in Table 1, in 1981, 71% of the crop farmers classified themselves as vegetable farmers, followed by root crop farmers (21%). This trend was similar for the next 15 years as shown by the data obtained in 1994-1995. However, six years later (2001), the trend showed that vegetable production was highly non-profitable (0.6%) and bananas were perceived to be the most profitable (46%) followed by root crops (42%). Based on the results of the survey, the physical land area devoted to each cropping enterprise had not changed, but because the demand for vegetables had reduced significantly with the reduction in the export markets, banana and root crops now provided the major portion of the income (data not shown).

In 1981, farmers identified labour (38%), pests and diseases (21%), the weather (19%), and marketing (13%) as their most serious constraints to production. In 1994-1995, pests and diseases (21%), marketing (16%), and praedial larceny (14%) were the most serious constraints. By 2001, the pattern of constraints had changed again, with marketing (28%), pests and diseases (25%), and access to inputs (15%) being the most serious constraints (Table 2). Throughout the three periods of the study, although farmers listed several other constraints, these were not significant to have an impact.

In 1981, farmers indicated that their main sources of information were radio (51%), extension officers (21%), and the agricultural stations (21%). By 1994-1995, most of the farmers identified extension officers (78%), followed by input suppliers and (or) marketing agents (26%), and other farmers (23%). In 2001, extension officers (58%), banana field workers (17%), and other farmers (9%) were the farmers' main soures of information.

Table 1 Number of farmers surveyed in St Vincent between 1981 and 2001 and classified according to their farming system

	No. of farmers surveyed			Per cent		
Type of agricultural system	1981	1994-1995	2001	1981	1994-1995	2001
Vegetable	107	42	1	71.3	39.62	0.6
Roots and tubers	32	20	72	21.3	18.87	42.3
Peanuts	2	—	—	1.3	—	—
Tree crops	1	2	1	0.7	1.89	0.6
Tobacco	1	—	—	0.7	—	—
Pigeonpea-legumes	1	5	—	0.7	4.72	—
Banana	6	15	78	4.0	14.15	45.9
Plantain	—	—	18	—	—	10.6
Livestock	—	15	—	—	14.15	—
Fruits	—	7	—	—	6.60	—
Total no. of farmers	150	106	170			

Table 2 Constraints to production by farmers surveyed in St Vincent between 1981 and 2001

	No. of farmers surveyed			Per cent		
Constraints to production	1981	1994–1995	2001	1981	1994–1995	2001
Labour	55	4	11	36.7	3.8	6.5
Pests and diseases	31	36	42	20.6	34.0	24.7
Weather	28	3	5	18.6	2.8	2.9
Marketing	20	17	47	13.3	1.6	27.6
Poor access roads	8	2	—	5.3	1.9	—
Unavailability of land	2	2	—	1.3	1.9	—
High cost of inputs	1	1	—	0.7	0.9	—
Low price of produce	1	—	—	0.7	—	—
Unavailability of transport	1	—	—	0.7	—	—
Access to credit	1	1	16	0.7	0.9	9.4
Praedial larceny	1	15	17	0.7	14.2	10.0
Lack of technological information	1	1	4	0.7	0.9	2.4
Damage to crops by animals	—	7	—	—	6.6	—
Access to inputs	—	—	26	—	—	15.3

Table 3 Sources of infomration obtained by farmers in St Vincent between 1981 and 2001

	No. of farmers surveyed			Per cent		
Source of information	1981	1994–1995	2001	1981	1994–1995	2001
Radio–Other mass media	77	8	—	51.3	16.9	—
Extension offices	32	83	99	21.3	78.3	58.2
Agricultural station	31	—	—	20.7	—	—
Other farmers	6	24	15	4.0	22.64	8.8
Relatives	4	10	—	2.7	9.43	—
Banana field workers	—	—	29	—	—	17.0
Traffickers	—	—	12	—	—	7.1
Input suppliers–Marketing agents	—	28	3	—	26.4	1.8
Friends	—	—	12	—	—	7.1
Banana Growers' Association	—	16	—	—	16.1	—
Chinese Agricultural Technical Mission	—	6	—	—	5.7	—

Antigua

The results of the study indicated that the average yield per hectare for tomatoes increased from 8000 kg annum-1 in 1997 to 15 000 kg annum^{-1} by 2000. Cabbage yield increased from 12 000 kg ha^{-1} in 1997 to 18 000 kg ha^{-1} by 2000, showing an increased production of 50%. Onion production showed an increase of 4800 kg ha^{-1} over the corresponding period from 12 000 to 16 800 kg ha^{-1} (data not shown).

With regard to adoption scores, the highest possible score that could be obtained was 230. The results showed 47.7% of the respondents obtained between 60 and 120, while only 18.6% attained scores above 120 (Table 4). The lowest score obtained was 16 and the highest was 207. The mean score obtained was 87.20 ± 44.55.

Based on the results of the survey, 37.2% of the farmers indicated that marketing was the main constraint to production and diversification efforts followed by praedial larceny (19.8%), pests (18.6%), rogue livestock (17.4%), and unavailable water for irrigation (12.8%; Table 5).

Table 4 Distribution of Antiguan farmers by knowledge

Knowledge/Adoption score	Number	Per cent
<60	29	33.7
60–120	41	47.7
>120	16	18.6
Total	86	100.0

Barbados

Among the farmers sampled in Barbados, 45.8% indicated that technical problems were their most serious constraint to production and diversification, followed by labour (33.6%) and agricultural policy (21.6%). Praedial larceny (19.2%), management (16.8%), markets (16.4%), and monkey damage (15.0%) were indicated as constraints as well (Table 6).

Farmers on this island were also requested to indicate how they obtained information on agricultural issues. Of the total number of farmers sampled, 50% obtained their information via the internet and other print media, while 38% sought their information from the Ministry of Agriculture. Approximately 16% sought information from fellow farmers, 15% did so from agricultural input suppliers, while 5% obtained their information from the Barbados Agricultural and Marketing Corporation (Table 7).

Trinidad

As shown in Table 8, the farmers in Trinidad identified availability and cost of labour to be the most severe constraint to production (50.8%) followed by bird and mammalian damage (45.0%), praedial larceny (39.2%), and plant disease (37.5%). Other factors that constrained agricultural production and diversification included weather conditions (21.7%), policy-related issues (21.7%), cost of inputs (12.5%), poor access roads (10.0%), marketing (9.2%), pest damage (7.5%), and lack of financial resources (6.7%).

Adoption behaviour was significantly correlated with encouragement of new entrants and of offspring into farming, willingness of existing farmers to improve their current methods of farming, investment and use in hiring labour, use of farm records, and farming status either full- or part-time (data not shown).

With regard to the issue of sourcing information, 42% of the farmers surveyed indicated their sources were Extension personnel belonging to the Ministry of Agriculture. Approximately 18% obtained their information from the media (print, radio, and television), while others indicated that they obtained their information from other farmers (2%), their spouse or other family members (1%), and agro-chemical salesmen (1%; Table 9).

Discussion

It has become clear for many years now, that the Caribbean Region has to diversify its agricultural production if the contribution of the sector to GDP is to be increased or even maintained (Gumbs, 1998). The major traditional commodities of sugar. banana, and rice have been severely constrained internationally as a result of the current liberalized market economy (Gumbs, 1998). Although the small island states have attempted to diversify their monocropping long-term enterprises to include more short-term intercropping enterprises, few successes have been reported. This was perceived to be mainly because of the lack of proper linkages and infrastructure with the more serious constraints being perishability and marketing.

Table 5 Problems outlined by Antiguan farmers as constraints to agricultural production and diversification

Nature of problem	Number	Per cent
Marketing	32	37.2
Praedial larceny	17	19.8
Pests	16	18.6
Roaming livestock	15	17.4
Unavailable water for irrigation	11	12.8
Drought	10	11.3

Table 6 Problems outlined by Barbadian farmers as constraints to agricultural production and diversification

Nature of problem	Number	Per cent
Technical	98	45.79
Labour	72	33.64
Policy	45	21.03
Paedial larceny	41	19.16
Management	36	16.82
Market	35	16.36
Monkey damage	32	14.95
Other	25	11.68

Table 7 Distribution of Barbadian farmers as constraints to agricultural production and diversification

Information sources	Number	Per cent
Internet, journals, print	106	49.5
Ministry of Agriculture and Rural Development	82	38.3
Other farmers	34	15.9
Agricultural input suppliers	33	15.4
Barbados Agricultural and Marketing Corporation	10	4.7

Table 8 Problems outlined by Trinidadian farmers as constraints to agricultural production and diversification

Nature of problem	Number[1]	Per cent
Availability and cost of labour	122	50.83
Parrot, monkey, woodpecker and squirrel damage	108	45.00
Praedial larceny	94	39.16
Plant diseases	90	37.50
Weather	52	21.66
Policy related issues	52	21.66
Cost of inputs	30	12.50
Poor access roads	24	10.00
Marketing	22	9.16
Pest damage	18	7.50
Lack of finance	16	6.66

[1] n = 240

Table 9 Distribution of Trinidadian farmers by information sources

Information sources	Number	Per cent
Ministry of Agriculture	101	42.0
Media	43	18.0
Another farmer	5	2.0
Spouse and (or) family	3	1.0
Agro-chemical salesman	3	1.0

All four of the islands studied indicated many constraints to agricultural production and to diversification. Some of the constraints are common but there are important differences.

Trinidad and Barbados reported that agricultural policy issues (22%) were constraints to production. But because of the nature of the economies of St Vincent and Antigua, the national agricultural policies of these two islands have always been advantageous to the small farmers and it was therefore not surprising that agricultural policies were not perceived to be negative. In St Vincent, in particular, the farmers are profit-oriented rather than subsistence-oriented (Henderson and Gomes, 1979; IFAD, 1993), and the agricultural policies were beneficial to the farmers.

Inspite of the favourable agricultural policies in St Vincent and Antigua diversification was not successful. In St Vincent over a period of 20 years the crop species diversification depended more on the profitability of the crop than on the constraints indicated in the survey. Farmers shifted their production (Table 1) to increase their profit.

It would appear that generally farmers in all four countries had access to information to reduce many of the important constraints to production but other factors limited diversification. Nevertheless, farmers in St Vincent and Antigua felt that the diversification programme embarked upon was not well publicized and that communication, in terms of providing them with operational details, were unsatisfactory. This suggests a need for improved communication, not only on the specific details of the programme but also with respect to markets, inputs, and other support services.

Trinidad was a different case because the focus of the diversification effort was not on small farmers but on public sector company with more capital outlay. Nevertheless, diversification failed in both models.

In conclusion, the constraints to production that the farmers perceived to be responsible for the failure of the diversification efforts, need to be addressed.

References

Blalock, Herbert, M. (1960) Social Statistics, New York, U.S.A., McGraw Hill Book Co. Ltd, pp. 395-397

Demas, William, G. (1987) Agricultural Diversification in the Caribbean Community: Some Issues, Seventh Annual Meeting of the Board of Governors, Grand Anse, Grenada, pp. 5-18

Freund, John, E. (1973) Modern Elementary Statis-tics, New Jersey, U.S.A., Prentice Hall Inc., pp. 449-450

Gumbs, F.A. (1998) Models for Caribbean Agricultural Diversification, Workshop Proceedings, 17-18 August 1998, St Augustine, Trinidad, CEPAT,The University of the West Indies, 148 pp.

Harry, E. (2002) The status and performance ofagricultural diversification in Trinidad and Tobago, in: Status and Performance of Diversification Initiatives of Caribbean States, Workshop Proceedings, 17-18 January, 2002, St Augustine, Trinidad, The University of the West Indies, pp. 40-45

Henderson, T.H. (1990) Farmer involvement and motivation for diversification programme implementation, in: Agricultural Diversification Policies and Strategies, Proceedings of the 19th West Indies Agricultural Economics Conference, p. 107110

Henderson, T.H. and Gomes, P.I. (1979) A Profile of Small Farming in St Vincent, Dominica, and St Lucia, St Augustine, Trinidad, Department of Agricultural Extension, The University of the West Indies, St Augustine Campus, pp. 37-40

IFAD (1993) A Baseline Survey of Small Farmers in St Vincent, Kingstown, St Vincent, W.I., Ministry of Agriculture

John, Karl (1996) Report of the Agricultural Rehabilitation and Diversification Project, Kingston, St Vincent, W.I., Ministry of Agriculture

Kentish, Florita, E. (2002) The status and performance of agricultural diversification in Antigua and Barbuda, in: Status and Performance of Diversification Initiatives of Caribbean States, Workshop Proceedings, 17-18 January, 2002, St Augustine, Trinidad, The University of the West Indies, pp. 1-5

Moser, C.A. (1969) Survey Methods in Social Investigation, London, U.K., Heineman, pp. 74-75

OECS (1980-1998) Annual Economic Reports, Castries, St Lucia, W.I., Organization of Eastern Caribbean States

Persaud, B.C. (1969) Agricultural diversification in the Commonwealth Caribbean: Some basic issues, in: Report of the Third West Indian Economic Conference, St Augustine, Trinidad, The University of the West Indies, St Augustine Campus

Robertson, R.H. (2002) Agricultural Diversification: The experience of St Vincent and the Grenadines and new challenges, in: Status and Performance of Diversification Initiatives of Caribbean States, Workshop Proceedings, 17-18 January, 2002, St Augustine, Trinidad, The University of the West Indies, pp. 35-39

Seltiz, Claire (1959) Research Methods in Social Relations, New York, Chicago, and San Francisco, U.S.A., Holt Reinhart and Winston, pp. 98-108

Smith, M.G. (1974) The Plural Society in the British West Indies, Berkley, Los Angeles, U.S.A., University of California Press, pp. 1-17

Statistical Trade Reports (1980-2000) Statistical Trade Reports, Kingstown, St Vincent, West Indies, Ministry of Finance and Economic Planning

Extracted from Volume 83, Number 3, 2006

Soil texture, mineralogy, and organic matter effects on structural stability and soil loss of selected Trinidad soils after rainfall

M.N. Wuddivira and R.J. Stone

Department of Food Production, Faculty of Science and Agriculture,
The University of the West Indies, St Augustine, Republic of Trinidad and Tobago, West Indies

E.I. Ekwe

Department of Mechanical and Manufacturing Engineering, The University of the West Indies,
St Augustine, Republic of Trinidad and Tobago, West Indies

Clay and organic matter both have cementing and binding abilities that play crucial roles in the formation and stability of soil aggregates. The interactions of clay and organic matter on the extent of differential swelling and the volume of entrapped air in soil aggregates during fast wetting both in the presence and in the absence of rainfall were investigated. The influence of clay mineralogy was also examined. The parameters assessed in the study were water-stable aggregates (WSA), final infiltration rate (FIR), runoff (Q), and soil loss (E). Samples from the surface (0-10 cm) of six agricultural soils in Trinidad with three levels of clay (low, <20%; medium, 20-45%; and high, >45%) and two of organic matter (low, 53% and high, >3%) were used. Generally, aggregate stability and infiltration rate increased while seal formation, runoff, and soil loss decreased with increasing clay content. The high clay, high organic matter sample dominated by high activity clay yielded the highest WSA (68.8%) and the smallest E (0.99 kg m^{-2}), whilst the low clay, low organic matter sample dominated by low activity clay minerals had the lowest WSA value (5.3%). The high cation exchange capacity (20.2 cmol kg^{-1}) of Oropuna, a high clay, low organic matter content soil, classified as kaolinitic, indicates the presence of appreciable quantities of smectites. Therefore, the significantly lower WSA (56.5%) and FIR (3.2 mm h^{-1}) and higher Q (100.6 mm) and E (5.59 kg m^{-2}) of Oropuna over Montserrat (WSA = 61.5%; FIR = 109.9 mm h^{-1}; Q = 6.3 mm; and E = 3.06 kg m^{-2}) and Godineau (WSA = 68.8%; FIR = 60.7 mm h^{-1}; Q = 41.3 mm; and E = 0.99 kg m^{-2}) medium and high clay smectitic soils high in organic matter demonstrates the importance of organic matter in alleviating clay dispersion and slaking in soils predominated by high activity expanding clays. The results also demonstrate that there is a threshold clay content above which the support of organic matter is required to weaken disruptive forces and below which organic matter and slow wetting are not effective in diminishing disruptive forces.

Keywords: Aggregate stability; Aggregate slaking; Seal formation; Fast wetting; Low and high activity clay; Clay content; Organic matter content; Simulated rainfall

High aggregate stability is crucial for the maintenance of adequate pore space for infiltration and desirable soil hydraulic properties. Aggregate stability expresses the soil's resistance to the destructive actions of wetting, raindrop impact, and other soil disturbances. Hence, the extent to which soil aggregates succumb to disruption will depend on the strength of cohesive forces holding the structural units together (Mbagwu and Bazzoffi, 1998) and the magnitude of disruptive forces in operation (Rengasamy and Sumner, 1998). Normally, when disruptive forces overcome cohesive ones, aggregates break down, hydraulic conductivity and infiltration rate decrease, runoff increases, and the likelihood of soil degradation through erosion becomes imminent (Spacini et al., 2004). Knowledge of binding factors which confer cohesive strength to the

0041-3216/2021/030302-311

soil aggregates to maintain structural integrity under continuous wetting and raindrop impact, is therefore important, particularly in the high rainfall of the humid tropics.

The main processes by which soil aggregates are disrupted upon rainfall are slaking, which is the disruption of aggregates due to the forces exerted by compressed air entrapped during re-wetting; differential swelling of clays; mechanical dispersion due to the kinetic energy of raindrops; and physico—chemical dispersion (Le Bissonnais, 1996). Rapid soil wetting and raindrop impact have been identified as the most important disruptive mechanisms (Geeves, 1997) that modify the number, shape, continuity, and size distribution of pores as well as the strength and stability of the soil (Lado et al., 2004). Geeves (1997) reported that fast wetting was the dominant agent causing aggregate breakdown when the soil was initially dry, whilst raindrop kinetic energy dominates on slow pre-wetting of aggregates. Exchangeable sodium percentage (ESP) is important in the physico—chemical dispersion of soil aggregates. Sodium on the exchange complex may negatively affect soil structure and aggregate stability (Abu-Sharar et al., 1987). Clay swelling and (or) dispersion and slaking of unstable aggregates increase at increasing ESP (Crescimanno et al., 1995).

In the Caribbean region, the agents of aggregate breakdown are very active. The rainfall of the region is high, ranging from 1270 mm to as high as 7600 mm yr^{-1}, and the rainfall intensities usually exceed 127 mm h^{-1} (Gumbs, 1982). Under these conditions, the susceptibility of soils to structural breakdown with attendant runoff generation and soil loss is increased. Also, the preponderance of soils of medium to heavy textures with low organic matter (OM) and low free iron oxides in the region, the ills of surface structural instability are accentuated (Ahmad and Roblin, 1971). The susceptibility of River Estate Series in Trinidad to crusting was a result of weak structure associated with very low OM (<1.5%), low free iron oxide contents, and micaceous nature of the soil minerals (Ahmad and Roblin, 1971). In the Caribbean region, therefore, the major challenge is to achieve an open aggregated structure to ensure adequate water movement and infiltration and sustaining it under continued wetting and raindrop impact.

Clay acts as a cementing material which holds particles together and thus protects aggregates against disruptive forces (Lado et al., 2004). Therefore, increasing the content of cementing materials results in increasing aggregate stability (Boix-Fayos et al., 2001). Alternatively, under fast wetting, an increase in clay content could also increase the extent of differential swelling and the volume of entrapped air (Zaher et al., 2005) which, in turn, increases aggregate slaking (Lado et al., 2004). In addition to clay content, clay mineralogy has a substantial effect on aggregate stability and dispersion. Smectites more readily form aggregates but can show extensive intra-crystalline swelling and dispersion on contact with water. The great swelling and shrinkage which may occur in smectitic clays on wetting and drying can render the aggregates less stable than those formed from kaolinite (Singer, 1994; Igwe et al., 1999). Wuddivira and Camps-Roach (unpubl.) showed the higher stability observed in kaolinitic dominated clays when compared to the smectitic dominated swellable clays in Trinidad.

Soil OM binds primary particles in the aggregate physically and chemically, and this in turn, increases the stability of the aggregates and limits their breakdown during wetting (Sullivan, 1990). Organic matter acts by (i) increasing aggregate cohesion resulting from adsorption of organic materials onto colloidal surfaces, (ii) decreasing the wettability of individual aggregates, and (iii) the occlusion of individual aggregate pores sensitive to slaking (Sullivan, 1990; Chenu et al., 2000; Zaher et al., 2005).

Most studies so far have focussed on the separate individual effects of OM or clay content on aggregate stability, with minimum research into the interactive effects of these parameters. Strong links have been established between aggregate stability and clay and OM (Levy and Mamedov, 2002). Nonetheless, the variations in reported relations between aggregate stability and clay or OM content suggest that aggregate stability cannot be inferred solely from clay or OM content. This study investigates the interactive effects of clay, OM contents, and clay mineralogy on soil aggregate stability, infiltration, runoff, seal formation, and soil loss.

Materials and Methods

Soils

Soil samples were taken from the top 0-10 cm of six agricultural soil series in Trinidad. Selection of soils was based on inherent clay and OM contents, since the other key factors affecting aggregation such as ESP and sesquioxides are generally low in Trinidad soils (Wuddivira and Camps-Roach, unpubl.). Trinidad is characterized by a humid tropical climate, with average annual rainfall that decreases from 3000 mm in the north to 1250 mm in the south. The wet season is from May to December which is often interrupted by a short dry spell, referred to as the *Petite Careme* (Gumbs, 1982). Soil classification, texture, and selected soil properties are presented in Table 1. All soil properties were determined by standard analytical methods described in Klute (1986) and Page et al. (1986).

Aggregate stability

The aggregate stability of the 1-2 mm size fraction of the samples was determined by wet sieving (Nimmo and Perkins, 2002). A single sieve apparatus with a stroke of 1.3 cm and a frequency of 34 cycles min^{-1} and two pre-wetting treatments were used: Prior to wet sieving in deionized water through a 0.25-mm sieve opening, 4-g triplicate samples of the 1-2 mm air-dried aggregates were either abruptly immersed in deionized water and allowed to stand for 10 min (fast wetting), or wetted slowly under tension by placing the sample on a filter paper in a tension table to saturate under 10 cm of water tension (slow wetting). Thereafter, the sieving commenced and continued for 15 min. The materials that passed through the sieve (unstable aggregates) were oven-dried at 105°C for 48 h. Sand particles >0.25 mm were separated from the material remaining on the sieve (stable aggregates) by dispersion with 0.02 M NaOH and the stable material passing through during dispersion was oven-dried. Aggregate stability was calculated as the mass of stable aggregates divided by the total aggregate (stable + unstable) mass, and expressed as the percentage of water-stable aggregates (sand free basis).

$$WSAf = [Ms/(Ms + Mu)] \times 100 \quad [1]$$

$$WSAs = [Ms/(Ms + Mu)] \times 100 \quad [2]$$

where, WSAf and WSAs are water-stable aggregates under fast wetting and slow wetting, respectively, Ms is mass of stable aggregates, and Mu is mass of unstable aggregates.

Infiltration and runoff studies

A continuous spray full jet nozzle (12.7 mm in diameter) attached to a Guelph Rainfall Simulator II (Tossell et al., 1990) was used to simulate rainfall of 120 mm h^{-1} intensity, which is common in Trinidad (Gumbs, 1982). Triplicate samples of air-dried

Table 1 Physical and chemical properties of the six soils used in the study

Soil properties	River Estate[1] (Fluventic Eutropepts)	Cleaver[2] (Orthoxic Tropudults)	St Augustine[3] (Orthoxic Tropudults)	Montserrat[4] (Typic Tropudolls)	Oropuna[5] (Aeric Tropaquepts)	Godineau[6] (Tropic Fluvaquents)
Clay (%)	19.4	17.5	35.3	43.3	63.3	67.3
Silt (%)	10.7	8.7	15.4	11.4	7.4	11.4
Sand (%)	69.9	73.8	49.3	45.3	29.3	21.3
Texture	Sandy loam	Sandy loam	Sandy clay loam	Sandy-clay	Clay	Clay
Organic matter (%)	2.3	3.7	1.4	3.9	1.8	6.9
Dry bulk density (Mg m^{-3})	1.4	1.5	1.5	1.0	1.4	0.8
CEC[7] (cmol kg^{-1})	4.2	7.7	10.5	27.1	20.2	33.4
ESP[8] (%)	4.5	7.6	0.7	0.8	0.5	1.1
pH in H_2O	4.3	6.4	6.4	5.9	4.7	3.4

[1]Low clay (<20%), Low organic matter (≤3%); [2]Low clay (<20%), High organic matter (>3%); [3]Medium clay (20–45%), Low organic matter (≤3%); [4]Medium clay (20–45%), High organic matter (>3%); [5]High clay (>45%), Low organic matter (≤3%); [6]High clay (>45%), High organic matter (>3%); [7]CEC, Cation exchange capacity; [8]ESP, Exchangeable sodium percentage

aggregates <5 mm in size were packed in columns 7.3 cm in diameter and 5 cm high and placed in the rainfall simulator at a slope of 9%. During each simulated rainstorm, water infiltrating through the soil was collected in measuring cylinders and the volumes were recorded at 5-min intervals for 60 min. Runoff (Q) was calculated as:

$$Q=S-Ic+H \quad [3]$$

where,

Q is total runoff in 60 min (mm), S is total depth of water supplied during 60 min simulated rainfall, Ic is cumulative infiltration (mm), and H is depth of water held by soil after 60 min of rainfall (mm). The soil loss (E) by splash and runoff over the period of 60 min was assessed by taking the dry weight of soil thrown out of the columns during rainfall, which is the difference in weight between the soil before and after the application of rain.

Statistical analysis

Three replicates of the studied parameters were run in a completely randomized design. Analysis of variance (ANOVA) was used to compare means. To study interactions for treatment effects on studied parameters, three levels of clay (low, <20%; medium, 20-45%; and high, >45%), and two of OM (low, <3.0% and high, >3.0%) were used in a 3 x 2 factorial combination. Soils with <3% organic matter are normally unstable (Guerra, 1994). Where significant interactions were observed, Tukey's Honestly Significant Difference at a single confidence limit was used to discriminate among the treatment means (Steel and Torrie, 1981). Also, regression analyses were performed in order to obtain relationships between dependent and independent variables and to extract best predictors for response variables.

Results and Discussion

Aggregate stability

The F values from ANOVA showed that the effects of clay and OM as well as their interaction on aggregate stability indices of WSAf and WSAs were significant (P < 0.001) (Table 2). The differences between the

Table 2 *F* Values of the analysis of variance (ANOVA) of the effects of clay and organic matter on stability indices and hydraulic properties

Source of variation	df	Measured parameters				
		WSAf	WSAs	Final infiltration rate	Runoff	Soil loss
Clay	2	5926.9[1]	440.8	791.9	257.0	13.4
OM[2]	1	2186.4	86.1	2164.8	713.4	6464.7
Clay × OM	2	82.8	40.4	411.2	121.1	13494.50

WSAf, Water stable aggregates (fast pre-wet); WSAs, Water stable aggregates (slow pre-wet); [1]*F* Values were significant for all parameters at $P \leq 0.001$; [2]OM, Organic matter

Table 3 Aggregate stability indices, final infiltration rate (FIR), runoff (Q), and soil loss (E) for the six soils

Soil sample	Measured properties					
	WSAf[1]	WSAs		FIR	Q	E
	%		ΔWSA	(mm h^{-1})	(mm)	(kg m^{-2})
River Estate	5.3	18.9	13.6	5.7	95.0	2.55
Cleaver	28.6	56.4	27.8	16.3	86.3	4.08
St Augustine	46.1	88.3	42.2	20.8	77.3	3.71
Montserrat	61.5	94.1	32.6	109.9	6.3	3.06
Oropuna	56.5	89.6	33.1	3.2	100.6	5.59
Godineau	68.8	93.8	25.0	60.7	41.3	0.99

[1]WSAf, Water stable aggregates (fast pre-wet); WSAs, Water stable aggregates (slow pre-wet)

soils with respect to the measured stability index of WSAf were significant (Table 3). This implies that the intrinsic soil properties of texture and OM content are important in the stability of these soils under fast wetting.

Aggregate stability results are presented in Table 3. In both low and high OM soils, aggregate stability increased with increasing clay content. The lowest WSAf value was obtained in samples belonging to the low clay category, followed by the medium clay category, and the highest value occurred in the high clay category (Table 3). The foregoing indicates the positive effects of clay in building aggregates and increasing the resistance of the soils to breakdown and slaking by water during fast wetting. Amongst the low clay content soils, WSAf was significantly higher in Cleaver, a low activity clay dominated soil high in OM content (3.7%) than River Estate, another low activity clay dominated soil low in OM content (2.3%; Figure 1 a). The clay mineralogy was important in determining the stability of aggregates in the medium to high clay soils to fast wetting. The stabilities of the medium clay soil (Montserrat) and the high clay soil (Godineau) which are both dominated by high activity clay minerals were not significantly different. However, they were both significantly higher than the medium (St Augustine) and high (Oropuna) clay content soils low in OM dominated by low activity clay (Figure I a). An earlier study conducted by Wuddivira and Camps-Roach (unpubl.) on some Trinidad soils varying in clay mineralogy and low in OM, revealed that kaolinitic soils were more stable than smectitic swellable clays. In this study, however, soils dominated by swelling clays and high in OM were more stable than soils dominated by kaolinitic clays low in OM. This implies that high OM content in swelling clay soils can lead to great structural integrity under fast wetting.

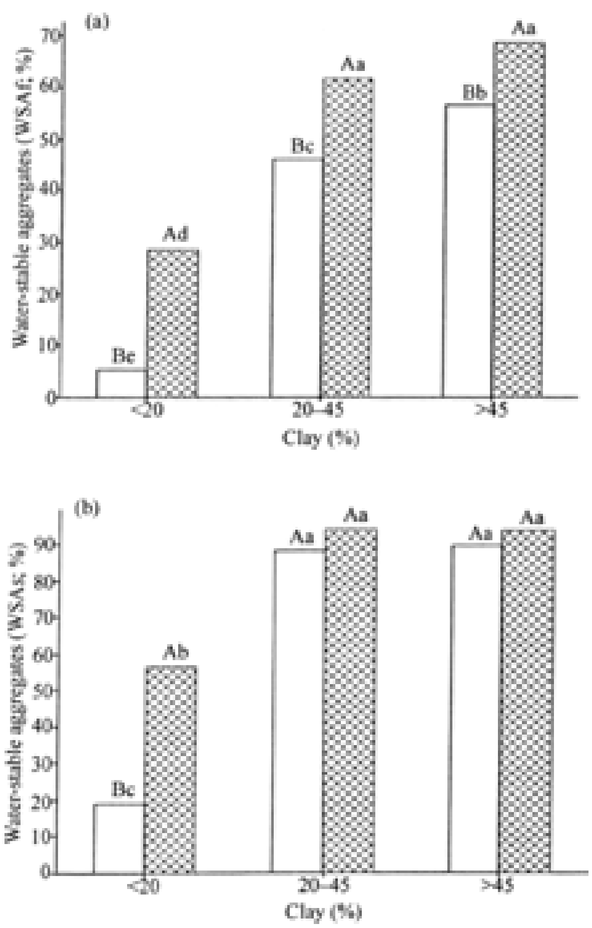


Figure 1 The effects of the interaction between clay and organic matter contents on (a) Water-stable aggregates, WSAf (fast pre-wet) and (b) Water-stable aggregates, WSAs (slow pre-wet). Values followed by dissimilar lower case letters within measured property and upper case letters within each clay level are significantly different at $P \leq 0.05$, Low organic matter level (≤3%), : High organic matter (>3%)

Montserrat, a medium clay, high OM soil had statistically significant higher WSAf over Oropuna, a high clay, low OM soil (Figure I a). This is an indication that clay content increases stability under fast wetting to a certain level above which it needs the support of OM to withstand the disruptive effects of fast wetting. Increase in OM content will improve cohesion and lower the wettability of aggregates and increase their resistance to slaking stresses (Chenu et al., 2000; Zaher et al., 2005). The statistical similarity of the WSAf of Godineau to that of Montserrat supports this fact and indicates that medium clay soils that are usually considered unstable can achieve comparable structural integrity to high clay, high OM soils if their OM content is high. From a practical standpoint, under the aggressive climatic conditions of the humid tropics, it is important to increase and maintain a high level of OM in medium clay soils and soils dominated by high activity clays that are often prone to disaggregation by fast wetting. This will increase the amount of air encapsulation within soil aggregates during fast wetting sufficiently to prevent slaking (Sullivan, 1990).

For each clay level, the aggregate stability by fast wetting of the high OM soils was significantly higher than that of the low OM soils (Figure la). Organic matter in the high OM soils encourages aggregation by increasing inter-particle cohesion within the aggregate. In the low OM soils, however, disaggregation stresses were strengthened resulting in extensive aggregate breakdown. The importance of clay in the stability of these soils is also shown by its significant relationship [Coefficient of Determination (R^2) = 0.63] with WSAf. Unlike the clay content, however, the regression of WSAf and OM content was low (R^2 = 0.13). This was because Cleaver, a low activity, low clay soil with high OM, had significantly lower WSAf value than the low activity clay samples with medium (St Augustine) and high (Oropuna) clay contents and low in OM. This may suggest that there is a threshold clay content below which OM is not effective in providing the cohesive force necessary to protect the soil aggregates against disruptive forces during the wetting process. The level of combination of clay and OM in a soil sample is therefore very important and cannot be dismissed even at high clay level.

Cation exchange capacity (CEC) positively correlated with WSAf (r = 0.84). The CEC was more closely related to aggregate stability than clay content. This supports the importance of the interaction between clay mineralogy and OM in the stability of these soils. The high activity clay soils with the largest values of CEC and OM (Table 1) (Montserrat and Godineau) had the largest WSAf (Table 3). Exchangeable sodium percentage negatively correlated with WSAf (r = —0.69), indicating that dispersibility of the studied samples increased with increase in this variable. The significantly negative correlation between WSAf and ESP was in spite of the generally low values of ESP in the soils (Table 1) and it shows that dispersion could occur in the soils even at low ESP values.

Slow pre-wetting significantly improved aggregate stability when compared with fast wetting. This is presumably due to the weakening of intra-aggregate pressure build-up, and thus, slaking by the gradual expulsion of air when aggregates were slowly wetted under tension. The soils at the medium clay level showed much greater improvement in stability as a result of slow wetting as shown by the AWSA, which is the difference between WSAs and WSAf (Table 3). Cleaver, a high OM low clay soil, had significantly higher WSAs than River Estate. Ahmad and Roblin (1971) linked the instability and high crustability of River Estate Loam to the micaceous nature of its minerals and low OM content. Both the stabilities of Cleaver and River Estate though significantly improved by slow wetting when compared to fast wetting, remained in the high instability class (Mbagwu, 1986). Though the medium to high clay soils had significantly higher WSAs over their low clay counterparts, there was, however, no statistical significance in the WSAs of medium and high clay soils irrespective of OM, clay mineralogy, and content (Figure 1 b). This shows that once the clay content is at the medium level, there is the tendency to achieve high structural integrity under slow wetting that could make the effects of clay content, mineralogy, and OM negligible. Therefore, slow wetting before application of water at faster rates will ensure sustainable structural integrity and productivity of medium to high clay soils by improving aeration and infiltration and reducing the rate of seal formation and subsequent runoff and erosion under intenserainfall. The aggregates in low clay soils, however, even at high OM level, will quickly form seals and generate high volumes of runoff under the devastating action of raindrop impact and intense rainfall.

This demonstrates that there is a threshold clay content below which slow wetting is not effective in improving structural stability sufficiently to alleviate the devastating action of intense rainfall. The stronger linear relationship of WSAs with ESP (r = —0.78) than WSAf with ESP (r = —0.69), however, suggests that at high sodicity levels, slow wetting may not be effective in reducing clay dispersion and slaking. This corroborates the findings of Levy et al. (2003, 2005) that soils at different sodicity levels exhibited low structural stability even at slow wetting. Therefore, agricultural practices that result in the build-up of sodicity must be avoided for sustainable productivity of these soils. Stepwise multiple linear regression analysis, including all independent variables to extract the most important predictors, revealed that clay and OM and the dispersing property of ESP are the most important predictors, accounting for 82% of the variability in WSAf (Table 4). Conversely, the dispersing property of ESP was the only and most important predictor accounting for 62% of variability in WSAs (Table 4).

Infiltration rate, seal formation, runoff, and soil loss

Results of surface hydraulic properties and soil loss are presented in Table 3. Aggregate stability under rainfall followed a slightly different trend to stability under fast wetting in the absence of rainfall. This is likely due to the disruptive effects of raindrop impact and fast wetting in operation under rainfall, as opposed to only fast wetting in the absence of rainfall. The multifactor analysis revealed that the main effects of clay and OM and their interaction were significant on FIR, Q, and E (Table 2).

Table 4 Step-wise multiple regression equations in the form of $Y = a + bx_1 + cx_2 + dx_3$ and Coefficient of Multiple Determination (R^2) relating measured processes (Y) and different soil properties (X)

Response parameter (Y)	Predictors	Regression equations a	b	c	d	R^2	Significance
WSAf [1]	Clay (x_1)	16.00	0.78			0.63	***
	Clay (x_1) and ESP (x_2)	29.40	0.57	–3.16		0.71	***
	Clay (x_1), ESP (x_2), and OM (x_3)	27.00	0.37	–4.86	4.86	0.82	***
WSAs	ESP (x_2)	94.10	– 8.23			0.62	***
FIR	OM (x_3)	–24.20	18.70			0.60	***
	OM (x_3) and ESP (x_2)	–19.50	20.20	–5.25		0.69	***
	OM (x_3), ESP (x_2), and Clay (x_1)	4.30	23.50	– 9.10	– 0.66	0.76	***
Q	OM (x_3)	121.00	–16.80			0.59	***
	OM (x_3) and ESP (x_2)	116.00	–18.20	5.07		0.70	***
	OM (x_3), ESP (x_2), and Clay (x_1)	91.30	–21.70	9.12	0.69	0.79	***
E	OM (x_3)	5.37	–0.64			0.37	*

*, ***, Significant at $P < 0.05$ and $P \leq 0.001$, respectively; WSAf, Water stable aggregates (fast pre-wet); WSAs, Water stable aggregates (slow pre-wet); FIR, Final infiltration rate; Q, Total runoff; E, Soil loss; ESP, Exchangeable sodium percentage; OM, Organic matter

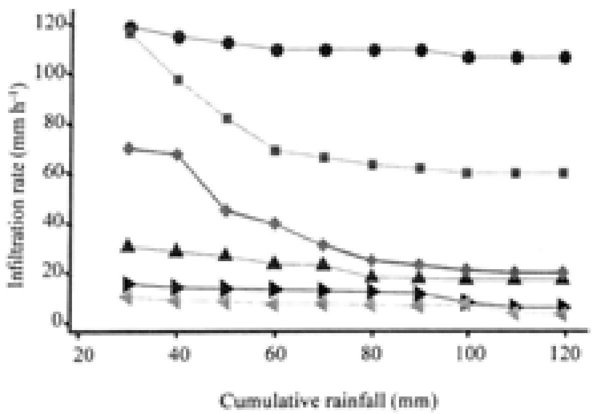


Figure 2 Infiltation rate as a function of cumulative rainfall for low, medium, and high clay soils at low and high organic matter (OM) levels. Clay: OM levels: ●, Medium–high; ■, High–high; ◆, Medium–low; ▲, Low–high; ►, Low–low; and ◄, High–low

In all soils, infiltration rate decreased with increase in cumulative rainfall until the attainment of a FIR (Figure 2). This decrease in infiltration rate with increase cumulative rainfall (Figure 2) is an indication of increasing soil structural degradation caused by slaking due to fast wetting and the destructive impact of raindrops on soil aggregates. The destruction led to aggregate breakdown and generation of finer particles that became substrate for seal formation. Once a seal was formed at the soil surface, the hydraulic conductivity of the soil layer was decreased, leading to low in filtration and high runoff. The faster a seal was formed, the lower the cumulative amount of water infiltrated until the attainment of FIR.

The rate of seal formation was fastest and of the same statistical magnitude in Oropuna when compared to River Estate (Figure 3a). Oropuna is high clay kaolinitic low OM soil, while River Estate is low clay micaceous soil (Smith, 1983) low in OM content. The high susceptibility of Oropuna to seal formation compared to the smectite dominated Montserrat and Godineau, disagrees with earlier studies that high structural stability and thinner crust occur on soils rich in kaolinite than those rich in smectites (Reichert and Norton, 1994; Singer, 1994; Wakindiki and Ben-Hur, 2002). However, the high CEC of Oropuna (20.2 cmol kg^{-1}) which would have been contributed basically by clay mineralogy since the OM content of this soil is low (Igwe et al., 1999), indicates the presence of appreciable amounts of smectites. Igwe et al. (1999) pointed out that those soils containing small amounts of these expanding minerals show weak structural stability. The high dispersibility of River Estate, however, agrees with previous reports that the dispersibility of illitic soils may sometimes exceed that of smectitic soils (Singer, 1994). Therefore, the high structural stability and slowest rate of seal formation in Montserrat and Godineau soils dominated by expanding smectitic clays must have been a consequence of decreased wettability and the stabilizing effect of high OM conferred to these soils.

soil loss were obtained in Oropuna (Table 3) indicating the weak stability of the soil under raindrop impact and wetting. Whilst the runoff of River Estate was on par with Oropuna (Figure 3b), its E was significantly lower ($P < 0.01$) than all other soils except for Montserrat and Godineau (Figure 3c). This would indicate that the seal formed on River Estate was strong enough to resist ease of removal of particles and aggregates from its surface by the detachable force of raindrops and runoff water. On the other soils, however, the slower rate of seal formation allowed the easier movement and subsequent loss of soil particles and aggregates by splash and in runoff. The apparent large-sized aggregates at the surface of Godineau at the end of 60 min of simulated rain, despite the lack of seal formation, appeared to be responsible for the low E.

Lado et al. (2004) reported a linear increase in aggregate slaking by fast wetting with an increase in clay content, and showed that with increase in clay content, there is an increase in the slaking mechanisms (e.g., differential swelling and explosion of entrapped air) that compensate for the increase in aggregate stability. In this study, however, the ability of OM to reduce pressure build-up by reducing the rate of water entry into individual aggregates suppressed slaking mechanisms during fast wetting. Thus, high stability and high infiltration rate are sustained when increase in clay is accompanied by increase in OM.

Soil OM showed a strong positive correlation ($r = 0.80$) with surface hydraulic characteristics of FIR and a strong negative correlation ($r = —0.80$) with Q. Organic matter accounted for up 60% of the variability in these processes. Stepwise multiple linear regression analysis, including all independent variables to extract the most important predictors, reveals that OM, ESP, and clay are the most important predictors accounting for 76 and 79% of the variability in FIR and Q, respectively (Table 4). This suggests that OM, sodicity, and clay are very important in the stability, seal formation, and runoff generation of these soils under intense rainfall. Since the aggregates experienced fast wetting during simulated rainfall, WSAf was the only stability index that significantly correlated ($r = 0.50$) with the surface hydraulic characteristics. However, the magnitude of correlation was smaller than expected. This could be as a result of fast wetting being the only operating disaggregation mechanism in the absence of rainfall, while both fast wetting and raindrop kinetic energy impact were operational under simulated rainfall.

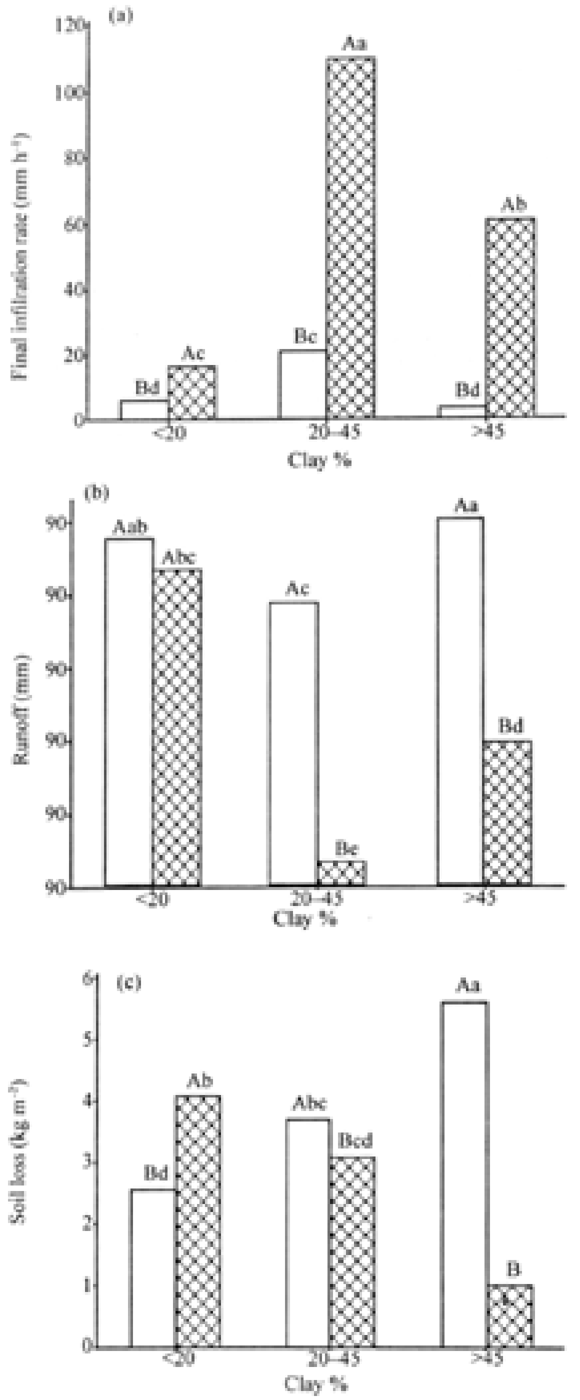


Figure 3 (a) Final infiltration rate, FIR, (b) total runoff, Q, and (c) soil loss, E, as functions of the effects of the interaction between clay and organic matter contents. Values followed by dissimilar lower case letters within letters within measured property and upper case letters within each clay level are significantly different at $P \leq 0.05$ level. □, Low organic matter level (≤3%); ▩, High organic matter level (>3%)

It can be concluded that for smectite-rich soils that are known to be unstable, maintenance of high OM is necessary to reduce wettability and subsequent incipient failure of aggregates due to swelling during fast wetting. The higher F value of the main effect of OM on FIR over clay supports this fact since these soils had larger FIR (Table 2). The highest runoff and

Conclusion

Clay and OM contents both increase aggregate stability under fast wetting, but the effect of clay content decreases at higher clay contents, while the effect of OM increases at higher OM contents. Moreover, clay mineralogy has a significant influence on aggregate stability such that higher activity clays are generally less stable than low activity clays. However, increasing the OM content of high activity clays can improve aggregate stability to a level, comparable to that of low activity clays with high OM contents.

There is a clay content threshold necessary for soils to achieve a high aggregate stability. Below this threshold, high levels of OM are not effective in providing the cohesive force necessary to protect soil aggregates against disruptive forces during the wetting process. Above this threshold, clay mineralogy and OM contents have negligible impact on further increasing aggregate stability. Additionally, above this threshold, increases in clay content and OM suppressed aggregate slaking, soil loss, and seal formation thereby facilitating increased infiltration rates under intense rainfall.

The practical implication of this study is that to avoid significant slaking, dispersion, aggregate breakdown, and soil loss in high clay soils and (or) soils dominated with high activity clays exposed to intense rainfall, the soil OM content must be maintained at high levels.

Ackowledgements

The authors are grateful to the Government of Trinidad and Tobago for funding a Commonwealth Scholarship to the first author, to Emeritus Professor Nazeer Ahmad for his invaluable technical advice, and to the technical staff of Food Production Department for assistance in the analytical work.

References

Abu-Sharar, T.M., Bingham, F.T. and Rhodes, J.D. (1987) Stability of soil aggregates as affected by electrolyte concentration and composition, *Soil Sci. Soc. Am. J.* 51 309-314

Ahmad, N. and Roblin, A.J. (1971) Crusting of River Estate soil, Trinidad, and its effect on gaseous diffusion, percolation, and seedling emergence, *J. Soil Sci.* 22 23-31

Boix-Fayos, C., Calvo-Cases, A., Imeson, A.C. and Soriano-Soto, M.D. (2001) Influence of soil properties on the aggregation of some Mediterranean soils and the use of aggregate size and stability as land degradation indicators, Catena 44 47-67

Chenu, C., Le Bissonnais, Y. and Arrouays, D. (2000) Organic matter influence on clay wettability and soil aggregate stability, *Soil Sci. Soc. Am. J.* 64 1479-1486

Crescimanno, G , Iovino, M. and Provenzano, G. (1995) Influence of salinity and sodicity on soilstructural stability and hydraulic characteristics, *Soil Sci. Soc. Am. J.* 59 1701-1708

Geeves, G.W. (1997) Aggregate breakdown and soil surface sealing under rainfall, Ph. D. thesis, Australian National University, Australia

Guerra, A. (1994) The effect of organic matter content on soil erosion in simulated rainfall experiments, Soil use Mgmt 10 60-64

Gumbs, F.A. (1982) Soil and water management features in Trinidad and Guyana, *Trop. Agric. (Trinidad)* 59 76-81

Igwe, C.A., Akamigbo, F.O.R. and Mbagwu, J.S.C. (1999) Chemical and mineralogical properties ofsoils in southeastern Nigeria in relation to aggregate stability, Geoderma 92 111-123

Klute, A. (ed.) (1986) Methods of Soil Analysis. Part I. Physical and Mineralogical Methods, 2nd edn, Agron. Monograph, 9, ASA and SSSA, Madison, WI, U.S.A.

Lado, M., Ben-Hur, M. and Shainberg, I. (2004) Soil wetting and texture effects on aggregate stability,seal formation and erosion, *Soil Sci. Soc. Am. J.* 68 1992-1999

Le Bissonnais, Y. (1996) Aggregate stability and assessment of soil crustability and erodibility: I. Theory and methodology, *European J. Soil Sci.* 47 425-437

Levy, G.J. and Mamedov, A.I. (2002) High-energy-moisture-characteristic aggregate stability as a predictor for seal formation, *Soil Sci. Soc. Am. J.* 66 1603-1609

Levy, G.J., Goldstein, D. and Mamedov, A.I. (2005) Saturated hydraulic conductivity of semiarid soils:combined effects of salinity, sodicity, and rate of wetting, *Soil Sci. Soc. Am. J.* 69 653-662

Levy, G.J., Mamedov,A.I. and Goldstein, D. (2003) Sodicity and water quality effects on slaking of aggregates from semi-arid soils, *Soil Sci.* 168 552-562

Mbagwu, J.S.C. (1986) Erodibility of soils formed ona catenary top sequence in southeastern Nigeria as evaluated by different indices, *East Africa Agric. For. J.* 52 74-80

Mbagwu, J.S.C. and Bazzoffi, P. (1998) Soil characteristics related to resistance of breakdown of drysoil aggregates by water drops, *Soil Till. Res.* 45 133-145

Nimmo, J.R. and Perkins, K.S. (2002) Aggregate sta bility and size distribution, in: Methods ofSoil Analysis, Part 4—Physical Methods. SSSA Book Series 5 (ed. Dick, W.A.), Soil Sci. Society of America, Madison, WI, U.S.A., pp. 317-328

Page, A.L., Miller, R.H. and Keeney, D.R. (eds) (1986)Methods of Soil Analysis. Part 2. Chemical and Microbiological Properties, 2nd edn, Agron. Monograph, 9, ASA and SSSA, Madison, WI, U.S.A.

Reichert, J.M. and Norton, L.D. (1994) Aggregate stability and rain-impacted sheet erosion ‘of air-dried and prewetted clayey surface soils under intense rain, *Soil Sci.* 158 159-168

Rengasamy, P. and Sumner, M.E. (1998) Processes involved in sodic behavior, in: Sodic Soils (eds Sumner, M.E. and Naidu, R.), U.K., Oxford University Press, pp. 35-50

Singer, A. (1994) Clay mineralogy as affecting dispersivity and crust formation in Aridisols, Transactions of the 15th World Congress of Soil Science, Vol. 8a (ed. Etchevers, J.D.), International Society of Soil Science and Mexican Society of Soil Science, Acapulco, Mexico, pp. 37-46

Smith, G.D. (1983) Correlation of the Soils of the Commonwealth Caribbean, Puerto Rico, The Virgin Islands and Guyana, Faculty of Agriculture, The University of the West Indies, Republic of Trinidad and Tobago

Spacini, R., Mbagwu, J.S.C., Igwe, C.A., Conte, P. and Piccolo, A. (2004) Carbohydrates and aggregationin lowland soils of Nigeria as influenced by organic inputs, *Soil Till. Res.* 75 161-172

Steel, R.G.D. and Torrie, J.H. (1981) Principles and Procedures of Statistics: A Biometrical Approach,London, U.K., McGraw-Hill

Sullivan, L.A. (1990) Soil organic matter, air encapsulation and water stable aggregation, *J. Soil Sci.*1 529-534

Tossell, R.W., Wall, G.J., Rudra, R.P., Dickson, W.T.

and Groenevelt, P.H. (1990) The Guelph raifall simulator II: Part 2. Comparison of natural and siulated rainfall characteristics, *Canadian Agric. Engineer* 32 215-223

Wakindiki, I.I.C. and Ben-Hur, M. (2002) Soil miner alogy and texture effects on crust micromorphology, infiltration and erosion, *Soil Sci. Soc. Am. J.* 66 897-905

Zaher, H., Caron, J. and Ouaki, B. (2005) Modeling aggregate internal pressure evolution following immersion to quantify mechanisms of structural stability, *Soil Sci. Soc. Am. J.* 69 1-12

SPECIAL ISSUE IN COMMEMORATION OF AGRICULTURAL LEGACY THROUGH TEACHING, RESEARCH AND INNOVATION
Extracted from Volume 89, Number 2, 2012

Development of a grafting protocol for the commercial propagation of three West Indian breadfruit cultivars

Frankie K. Solomon Jr.[1] and Laura B. Roberts-Nkrumah
Department of Food Production, The University of the West Indies, St. Augustine Campus, St. Augustine, Trinidad and Tobago, W.I.

Judy A. Rouse-Miller
Department of Life Sciences, The University of the West Indies, St. Augustine Campus, St. Augustine, Trinidad and Tobago, W.I.

[1]Corresponding author: e-mail Frankie.SolomonJr@sta.uwi.edu and phone 662-2002, Ext. 82090

Grafting breadfruit (*Artocarpus altilis*) on chataigne (*Artocarpus camansi*) rootstock can potentially benefit commercial establishment of breadfruit, but a suitable protocol needs to be developed. The objective of this study was to evaluate the effect of the grafting technique (whip and tongue, spliced side and top wedge), rootstock age (6, 9 and 18 week old), scion cultivar (two breadfruit cultivars from Trinidad- 'Yellow' and 'White', a Jamaican accession- 'JA1', and chataigne as the control) and season on grafting success. There were significant ($p < 0.05$) differences in length of survival neither among grafting technique nor rootstocks of different ages. Among scion cultivar, 'White' and chataigne scions generally survived longer ($p < 0.05$) than those of other cultivars. Grafting done in the wet season had significantly ($p < 0.05$) higher survival rate compared to those done in the dry season. Although not directly evaluated, scion quality and post-grafting environment were two factors that emerged as important to grafting these two species. The data suggest that season of grafting, scion quality and post-grafting environment were important determinants of grafting success. Scion harvested from juvenile mother plants during the wet season, matched with rootstock of similar diameter and grafted plants maintained in an environment which minimize water loss for both scion and rootstock for at least 4 weeks after grafting were essential for successful grafting of these selected breadfruit cultivars. When all these requirements were met, survival percentages of 97%, 83%, 80% and 80% for 'White', 'JA1', 'Yellow' and chataigne, respectively, were achieved.

Keywords: Grafting factors, Moraceae, breadnut, scion, rootstock

The Caribbean Community is highly dependent on imported food, which consists primarily of rice, wheat and corn (Wickham 2001, 11) which undermines food and nutrition security. This situation can be minimized through the development of carbohydrate rich crops, such as breadfruit. Fruits of this crop consist of a high percentage of carbohydrate (84%), appreciable quantities of calcium, magnesium, iron, potassium and phosphorus compared with other traditional staple starch crops and are a good source of riboflavin and niacin (Graham and Negron de Bravo 1981, 538; Jones 2010, 31). Furthermore, Roberts-Nkrumah (1998, 33) reported an annual estimated yield potential of 50,000 kg ha^{-1} for 4 to 5 years-old trees.

However, for the commercial production of breadfruit, focus must first be placed on developing a propagation method that can provide adequate quantities of good quality planting material in a rapid and sustainable manner. Due to triploidy of the seedless types, asexual propagation methods must be used (Ragone 2001, 693). Root cuttings and excised adventitious shoots (a modification of root cuttings) are the two methods being used currently by commercial nurseries in Jamaica and Trinidad and

0041-3216/2021/030312-325

Tobago, respectively (Roberts-Nkrumah 1993, 24; Webster 2006, 33). Although the latter method can produce many more plants in a much shorter time than the root cuttings, both of these methods cause harm to the parent plant when roots are harvested, increasing the entry of pathogens via wounded areas. Another constraint is that tree decline caused by either biotic or abiotic factors or both (Zaiger and Zentmyer 1966, 896; Trujillo 1971, 8; Weir et al. 1982, 20; Hodges and Tenoria 1984, 335; Coates-Beckford and Pereira 1992, 62) affects established trees in some parts of the region. These problems can thwart the potential contribution of breadfruit to food security, therefore better propagation methods are necessary.

However, there is no evidence that tree decline affects chataigne (*A. camansi*), a close seed-producing relative of breadfruit. Furthermore, the results of a survey conducted in Trinidad and Tobago showed that although the tree populations of both species were highest in wetter regions, chataigne was more widely adapted, possibly because of its tap root system. Thus, more trees of chataigne grew in the drier regions than those of the breadfruit (Roberts-Nkrumah, pers. comm.).

Grafting breadfruit onto chataigne rootstock has potential for commercial production, since it eliminates damage to the roots of parent trees, could increase distribution of the breadfruit trees to drier regions, and more plants can be produced in a shorter period compared to methods of propagation currently used (author's observation).

Although chataigne is thought to be a parent of breadfruit (Zerega et al. 2004, 765), variable levels of success have been achieved by grafting these species, and the requirements for a successful graft union have not been elucidated. Galang and Elayda (1924, 204) and Padolina (1931, 350) reported grafting breadfruit on chataigne using the inarching method. Inarching requires established plants to be used as scion material (Hartmann et al. 2011, 464), which would rely on other vegetative propagation methods and is not very efficient for commercial production. Rowe-Dutton (1976, 252) cited Wester as reporting no success in their attempt to graft these two species.

In an evaluation of the effect of rootstock age, Medagoda and Chandrarathna (2007, 151) reported 83% success on 45-day-old rootstock using top wedge grafting. Studies on grafting Jackfruit (*Artocarpus heterophyllus*) and *Artocarpus lakoocha* showed that factors such as grafting method, rootstock age, grafting environment, juvenility of scion material and season of grafting affected successful grafting (Kelaskar et al. 1991, 58; Kelaskar et al. 1993, 113; Islam et al. 2003, 1047; Sharma and Thakur 2005, 259; Mannan et al. 2006, 77; El-Zaher 2008, 1; Selvi et al. 2008, 341). The objective of this study was to examine the effect of grafting technique, rootstock age, season of collection of scion material and cultivar on grafting success.

Materials and Methods

This study was conducted during the period February 2006 to March 2010 at the University of the West Indies, St. Augustine Campus Trinidad and Tobago W.I. using planting material from the breadfruit germplasm collection at the University's Field Station (Roberts-Nkrumah 1998, 39). The study examined the effect of grafting technique, rootstock age, season of collection of scion material and cultivar on grafting success. These factors were examined progressively in six experiments based on the results of previous experiments.

Experiment 1 examined the effect of grafting technique (whip and tongue, spliced side and top wedge) and age of rootstock (6, 9 and 18 week old). The breadfruit scion material for this experiment consisted of epicormic shoots. Epicormic buds, on the lower branches of selected breadfruit trees were forced to break dormancy by bending the distal end of the branches to approximately 30 - 60 cm from the ground level. Five (5) cm long horizontal cuts at 15 cm apart were made through the bark along the upper surface from the proximal to the distal end of these branches. After, 7 – 8 weeks epicormic buds that developed into shoots were selected as scion material. These shoots ranged between 8 - 9 mm in diameter and 9 - 11 cm in length and with approximately 3 dormant axillary buds and terminal bud. For the rootstock, chataigne seeds with approximately 0.5 cm of the embryo emerging were selected from freshly harvested ripe fruits and soaked in Mankocide™ solution (Copper Sulphate as its active ingredient) (7g/L) for 5 to 7 minutes. The seeds had an average weight, length and width of 7.7g, 3 cm and 2 cm, respectively. The chataigne seedlings were established in potting bags with a soil mixture consisting of soil: manure: sharp sand in a 3:2:1 ratio, and placed under shade in a greenhouse and watered once daily. Grafting was done above or at the first node in the green to brown region of the rootstock. After grafting the entire plant and potting bag was covered with clear plastic bags and placed on benches under shaded (70%) greenhouse conditions.

A completely randomized design was used for the 9 treatment combinations, each with 30 replicates.

Experiment 2 examined the effect of cultivar on successful grafting. The cultivars were two breadfruit cultivars from Trinidad- 'Yellow' and 'White', a Jamaican accession- 'JA1', and chataigne as the control. Epicormic shoots were used as scion material. These shoots were derived from buds that broke dormancy by removing terminal buds of lower lateral branches of mature trees. The scion material was of similar morphology to those described in experiment 1 and the material was 5 – 6 weeks old. Breadfruit scion materials were grafted using top wedge onto 6-week-old chataigne rootstocks, which were grown in potting bags containing a soil mix. Six week old chataigne rootstock and the top wedge grafting technique remained constant for all subsequent experiments. After grafting, the entire grafted plant and potting bag were covered with a plastic bag and placed under similar post-grafting conditions as Experiment 1. The four treatment cultivars were replicated 20 times.

The objectives of Experiments 3 and 4 were to re-examine the effect of cultivar and to determine the effect of season in which the scion was collected and in which grafting was done on the successful grafting of breadfruit and chataigne. Scion material for Experiment 3 and Experiment 4 was collected in wet and dry season, respectively. The scion material consisted of axillary shoots collected from juvenile adventitious breadfruit plants, that is, suckers that had not borne fruit, or from chataigne seedlings in the field.

Approximately 6 to 7 weeks after pruning the terminal buds of these adventitious plants and seedlings, the dormant axillary buds that developed into shoots were harvested as scion material. These shoots harvested for Experiment 3, had also been pruned of their terminal buds and ranged 6 to 7mm in diameter and 8 to 10 cm in length, consisted of 3 to 4 developing secondary axillary buds. Although the scion material source was similar for Experiment 4, the material ranged from 7 and 9 mm in diameter, 8 and 9 cm in length, with 3 to 5 developing axillary buds. With the need to increase efficiency and utilize greenhouse space, chataigne seeds were established in a cone tray system (a seedling tray comprised of cone shaped cells), which had a depth of 21 cm and a top diameter of 3.8 cm with Promix™ used as the planting medium.

After plants were grafted in Experiment 3, they were covered with a transparent plastic bag and tied below the graft union. This was also done for the grafted plants of Experiment 4. However, due to the rapid drying out of the medium observed in Experiment 3, the grafted plants in Experiment 4 were placed in a propagation bin with intermittent misting.

The experimental design and number of replicates were similar to those of Experiment 2. Furthermore, the data for Experiment 3 and 4, were pooled to check the factor of season (wet and dry).This was also done for Experiment 5 and 6.

Experiments 5 and 6 repeated the effect of cultivar and season of scion collection and was conducted during the subsequent wet and dry season, respectively of Experiment 4. The preparation of both scion and rootstock was similar to that in Experiments 3 and 4, except that Ray Leach Single cell Cone-Tainers™ were used for the establishment of the chataigne seedlings. In Experiment 5, the scion material ranged between 6 and 7 mm in diameter, 7 and 8 cm in length, with approximately 3 developing axillary buds and terminal buds removed. The rootstock had a diameter range of 5.5 – 7.0 mm in diameter. Additionally, the post-grafting environment was modified to maintain a relative humidity (RH) of over 95% using intermittent misting and shade reduction of 75%. The scion material collected for Experiment 6, ranged between 7 and 8 mm in diameter 6 and 7 cm in length with 3 – 4 nodes, consisted of shoots that developed much more slowly than those used in Experiment 5 and had shorter internodes and thicker diameters.

In all experiments the numbers of surviving grafts were counted weekly, the data were analysed using ANOVA, and least significant difference (LSD at $P \leq 0.05$) was determined with the Statistical Package for Social Sciences (SPSS) version 17.

Results

Grafting technique and rootstock age

In Experiment 1 the grafted scions were short lived, survived only for approximately 4 weeks and there were no significant differences ($p < 0.05$) in the length of survival of grafted scion among grafting techniques or rootstocks of different ages. In addition, there was no interaction between these two factors (Table 1).

Cultivar

The results of Experiment 2 showed that cultivar significantly ($p < 0.05$) affected the length of survival of the grafted scion. The grafted scions of the 'White' breadfruit cultivar and of chataigne, the control, survived the longest, 7.8 and 6.8 weeks, respectively followed by JAI (4.9 weeks) (Table 2). The 'Yellow' scions survived for the shortest period, 2.6 weeks, while those of 'JA1' were intermediate, 4.9 weeks. Eight weeks after grafting the survival percentage of grafted plants was 90%, 75%, 25% and 15% for 'White', chataigne, 'JA1' and 'Yellow', respectively (Fig. 1). Although grafted plants survived beyond seven weeks, these plants, in subsequent weeks toppled due to detachment of the shoot system from the root system at the point of the cotyledon attachment.

Table 1: Effect of grafting technique on the length of survival of grafted scions on rootstocks of different ages- Experiment 1

Rootstock Age	Mean ± SE Length of Survival (weeks)			Rootstock Means (p = NS)[z]
	Grafting Technique			
	Whip and Tongue	Side	Top Wedge	
7 wk	3.4 ± 0.4	4.1 ± 0.4	3.3 ± 0.4	3.6 ± 0.2
9 wk	4.1 ± 0.4	4.3 ± 0.4	4.6 ± 0.4	4.3 ± 0.3
18 wk	3.8 ± 0.4	3.7 ± 0.4	4.2 ± 0.4	3.9 ± 0.3
Grafting Technique Means (p = NS)[z]	3.7 ± 0.2	4.0 ± 0.2	4.0 ± 0.2	-

Table 2: Effect of cultivar on the length of survival of breadfruit and chataigne scions at eight weeks after grafting – Experiment 2.

Scion Cultivar	Mean ± SE Length of Survival (weeks)
	Experiment 2 Wet Season
'Yellow'	2.6c[z] ± 0.4
'White'	7.8a ± 0.4
'JA1'	4.9b ± 0.5
Chataigne	6.8a ± 0.5
Cultivar Mean	5.5 ± 0.21

[z]Within column means followed by the same letter are not significantly different ($P > 0.05$) by LSD (0.80)

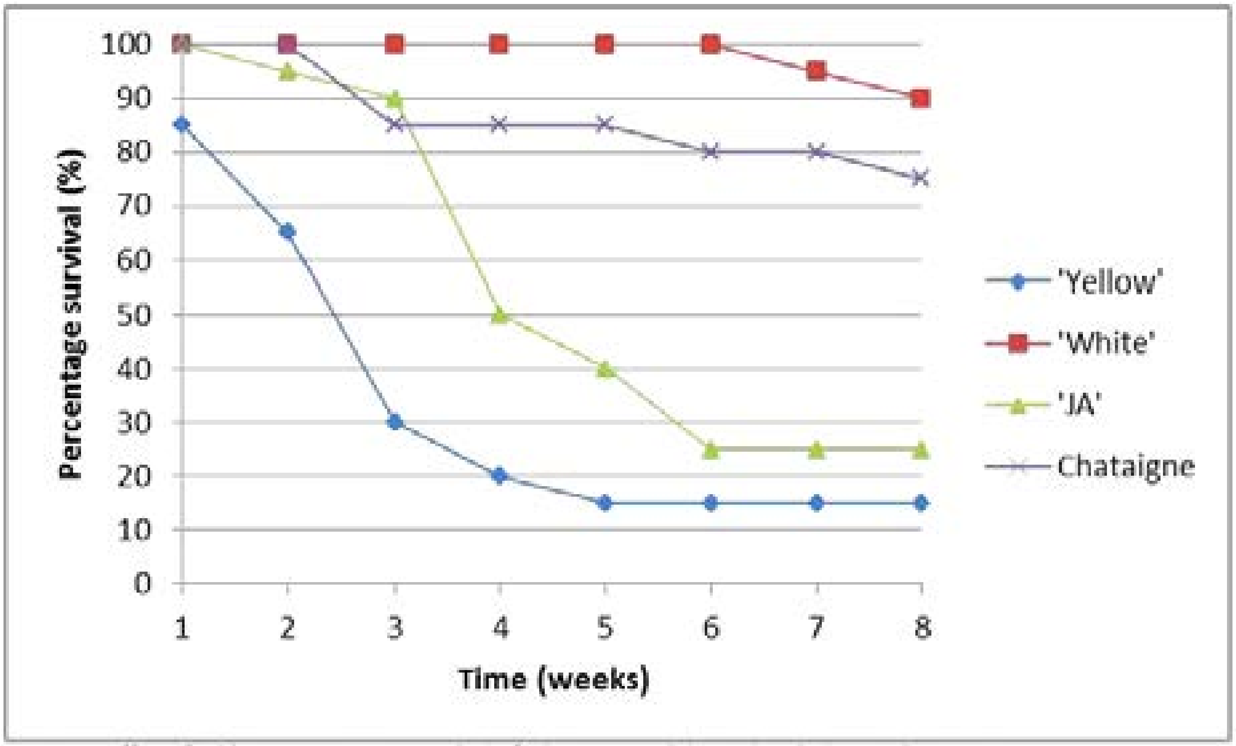


Figure 1 Effect of cultivar on percentage survival of scion over an eight week period- Experiment 2

The response to cultivar in Experiment 3 was different during the subsequent wet season to the one in which the Experiment 2 was conducted. Chataigne accounted for the highest mean length of survival (3.4 weeks) among other cultivars (Table 3). This was followed by 'JA1' with 1.4 weeks and both 'Yellow' and 'White' with 0.9 weeks, respectively. Results showed that cultivar had a significant ($p < 0.05$) effect on the length of survival of the grafted scion, with chataigne and JAI significantly ($p < 0.05$) different from all other cultivars. However, there were no significant ($p < 0.05$) differences observed between 'Yellow' and 'White' (Table 3). The survival percentage of grafted scions five weeks after grafting for chataigne and each of the selected breadfruit cultivars were 73% and 0, respectively (Fig. 2). Cultivar had a significant ($p < 0.05$) effect on mean length of survival of the grafted scion in Experiment 4. 'White' accounted for the highest length of survival, 2.4 weeks, followed by chataigne with 2.0. However, there were no significant ($p<0.05$) differences among 'White' and chataigne (Table 3). The survival percentages were 43%, 26%, 20% and 3% for 'White', chataigne, 'JA1' and 'Yellow', respectively (Fig. 3).

Table 3. Effect of scion cultivar on the length of survival of breadfruit and chataigne scions at four weeks after grafting – Experiment 3 and 4

	Mean ± SE Length of Survival (weeks)	
Scion Cultivar	Experiment 3 Wet Season	Experiment 4 Dry Season
'Yellow'	0.9c[x] ± 0.2	1.3c[y] ± 0.3
'White'	0.9c ± 0.2	2.4a ± 0.3
'JA1'	1.4b ± 0.2	1.7b,c ± 0.4
Chataigne	3.4a ± 0.3	2.0 a ± 0.4
Season Mean (NS)[z]	1.7 ± 0.2	1.9 ± 0.23

[x] Within column means followed by the same letter are not significantly different (P > 0.05) by LSD (0.44)
[y] Within column means followed by the same letter are not significantly different (P > 0.05) by LSD (0.50)
[z] P value not significant (p > 0.05)

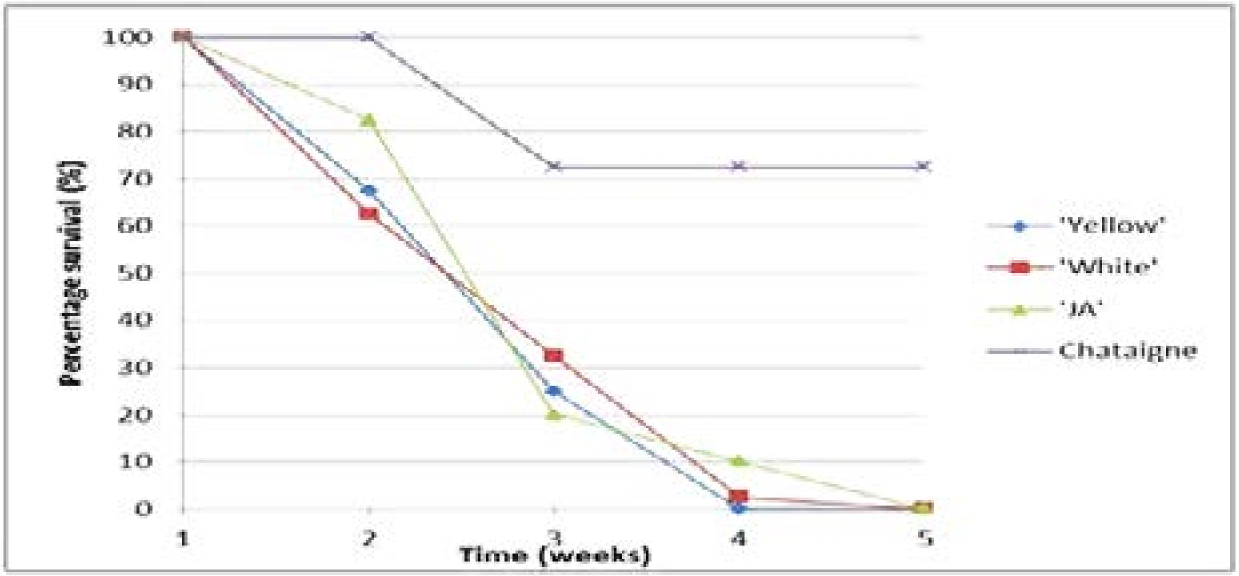


Figure 2: Effect of cultivar on percentage survival of scion over a five- week period-Experiment 3

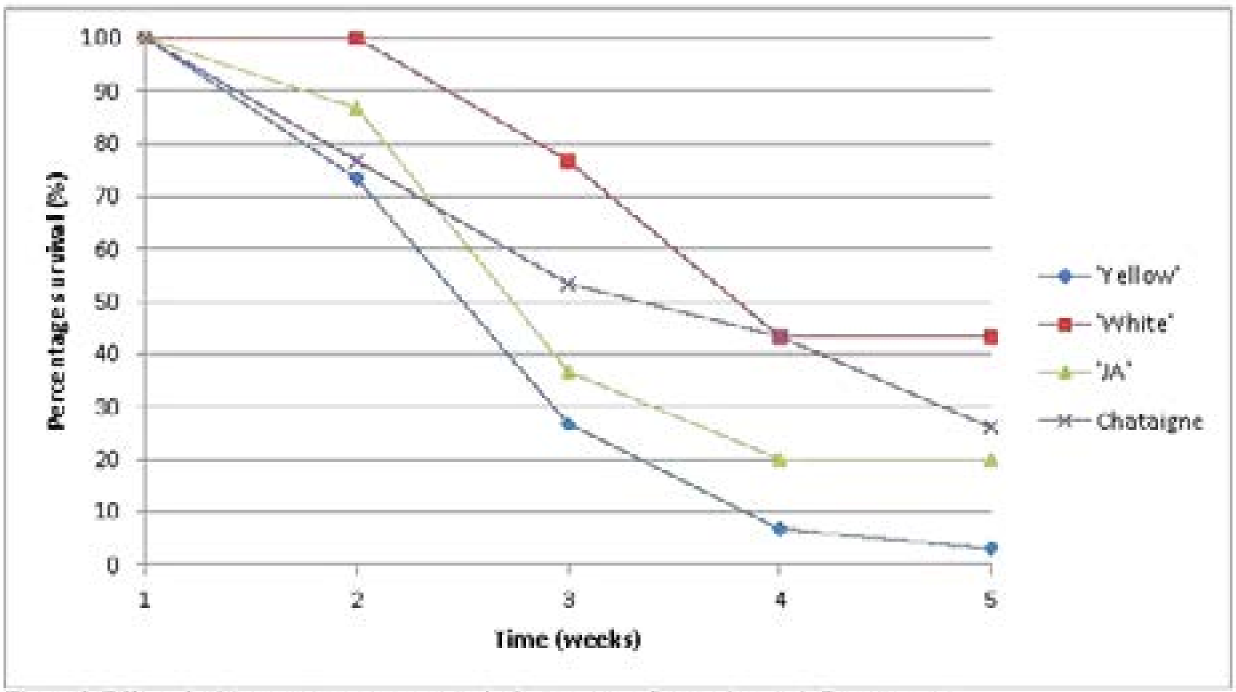


Figure 3: Effect of cultivar on percentage survival of scion over a five week period- Experiment 4

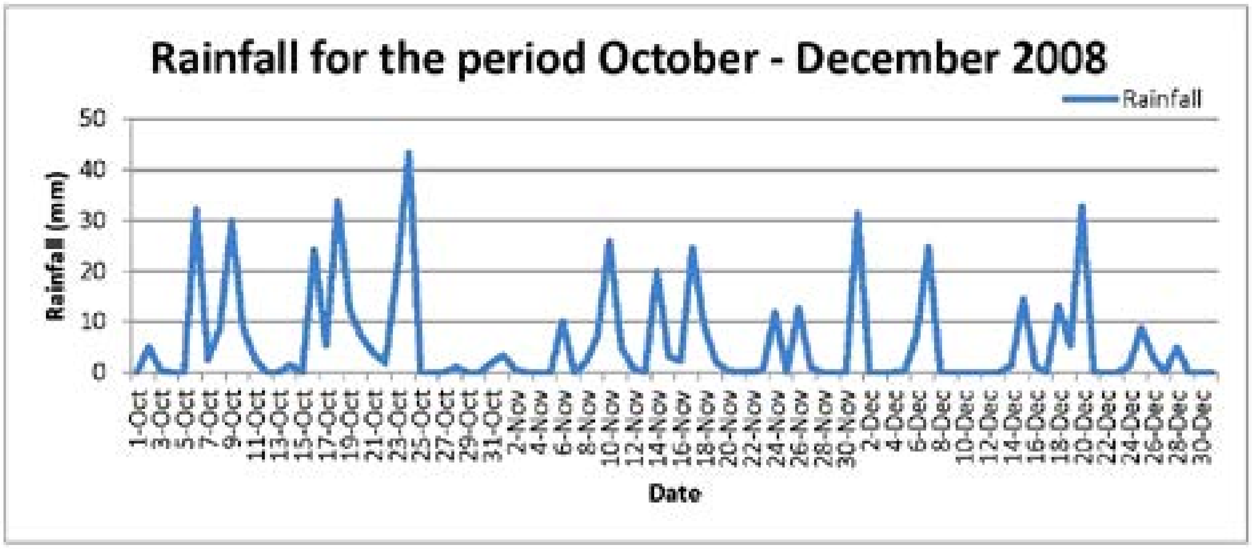


Figure 4: Rainfall pattern for a three-month period prior to collecting scion for Experiment 3 from parent source plants

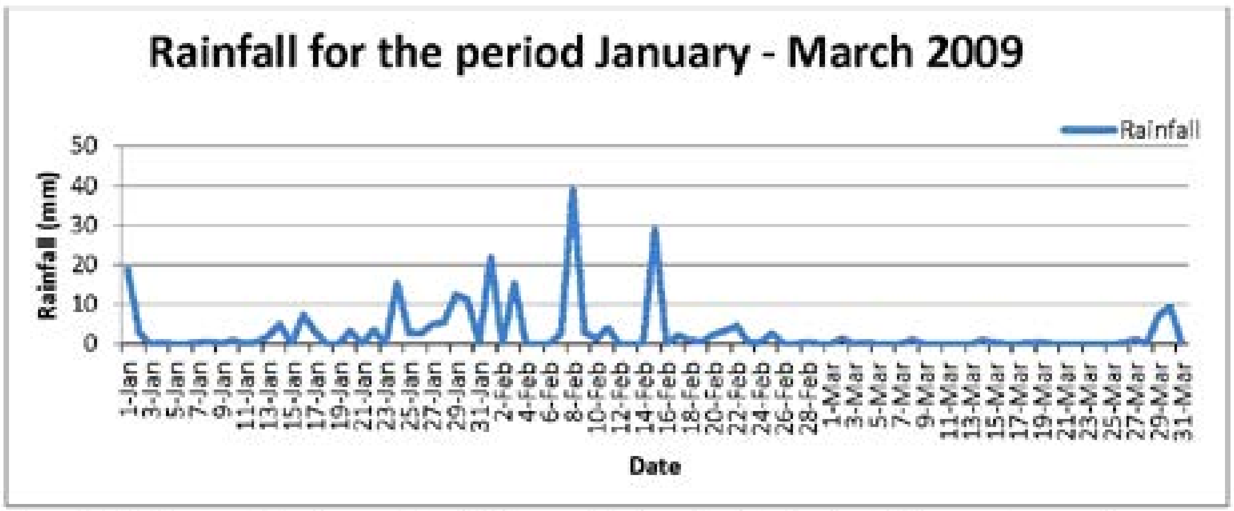


Figure 5: Rainfall pattern for a three month period prior to collecting scion for Experiment 4 from parent source plants

Table 4: Effect of time of grafting on length of survival of breadfruit and chataigne scions at six weeks after grafting

	Mean ± SE Length of Survival (weeks)	
Scion Cultivar	Experiment 5 Wet Season	Experiment 6 Dry Season
'Yellow'	$5.5^{x} \pm 0.4$	$2.5^{x} \pm 0.2$
'White'	5.9 ± 0.4	2.3 ± 0.1
'JA1'	5.4 ± 0.3	2.1 ± 0.2
Chataigne	5.3 ± 0.5	2.4 ± 0.3
SeasonMean[y]	$5.5a \pm 0.13$	$2.3b \pm 0.16$

[x] Within column means are not significantly different ($p < 0.05$) by LSD (0.56).
[y] Within row means followed by the same letter are not significantly different ($p > 0.05$) by LSD (0.41).

Cultivars had no significant ($p < 0.05$) effect on mean length of scion survival in Experiments 5 and 6, respectively (Table 4).

Season of scion material collection

The response to the effect of season of scion collection on the success of grafting was variable. The lengths of survival for Experiments 3 and 4 were lowest among all experiments. The lengths of survival were significantly ($p < 0.05$) different between Experiments 5 and 6 in which the scion material was collected in wet season (December) and in dry season (March), respectively (Table 4) with mean survival being 5.5 weeks and 2.3

weeks, respectively. The performance of the grafted scions was similar in Experiments 5 and 2, whereas scion survival in Experiment 6 was similar to that in Experiments 3 and 4. The factor of season did not have any significant ($p < 0.05$) effect on variation of the response. The rainfall pattern for the three-month period prior to collecting scion material in the field for Experiment 3 showed a fairly even distribution (Fig. 4). However, in the three-month period prior to collecting the scion material in Experiment 4 the pattern fluctuated during the first two months followed by a dry spell up until scion material was collected (Figs. 4 and 5).

The cultivar effect in Experiment 5 (wet season) displayed an overall mean length of survival of 5.5 weeks, which was similar to results of Experiment 2. 'White' accounted for the highest length of survival, 5.9 weeks, followed by 'Yellow', 'JA1' and chataigne with 5.5, 5.4 and 5.3, respectively (Table 4). Although grafted plants had an overall mean length of survival of 5.5 weeks, beyond the fifth week, grafted plants maintained their current survival percentages (Fig. 6). However, 'Yellow', showed decline during the fifth and sixth weeks and then leveled off. At the end of the seventh week the survival percentages of 'White', 'JA', and both 'Yellow' and chataigne were 97%, 83% and 80%, respectively (Fig. 6).

However, in Experiment 6 (dry season) the cultivar effect on the variation of the response was comparable to the results of Experiment 4, with an overall 2.3 weeks mean survival for cultivars (Table 4). There were sharp decreases in the percentage survival among cultivars during the second and third week followed by steady decline up until the fifth week, where data collection stopped (Fig. 7). The percentage survival for chataigne, 'Yellow', 'White', and 'JA1' were 20%, 15%, 15% and 5%, respectively (Fig. 7).

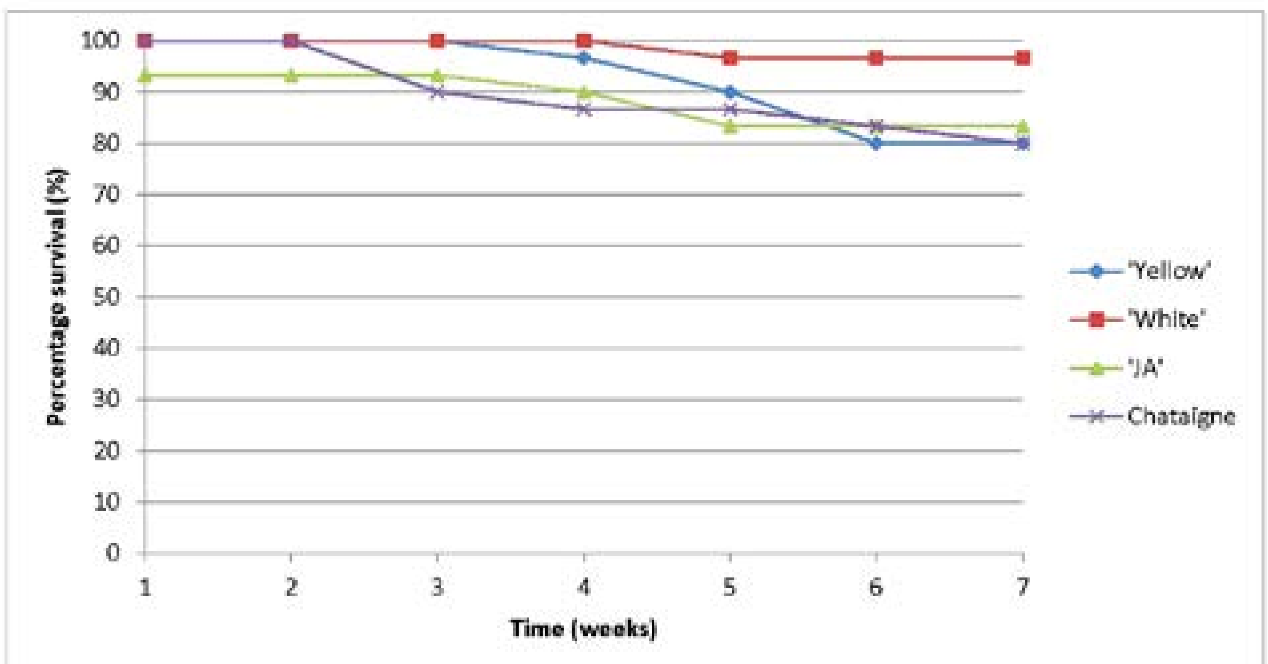


Figure 6: Effect of cultivar on survival percentage of scion over a seven week period- Experiment 5

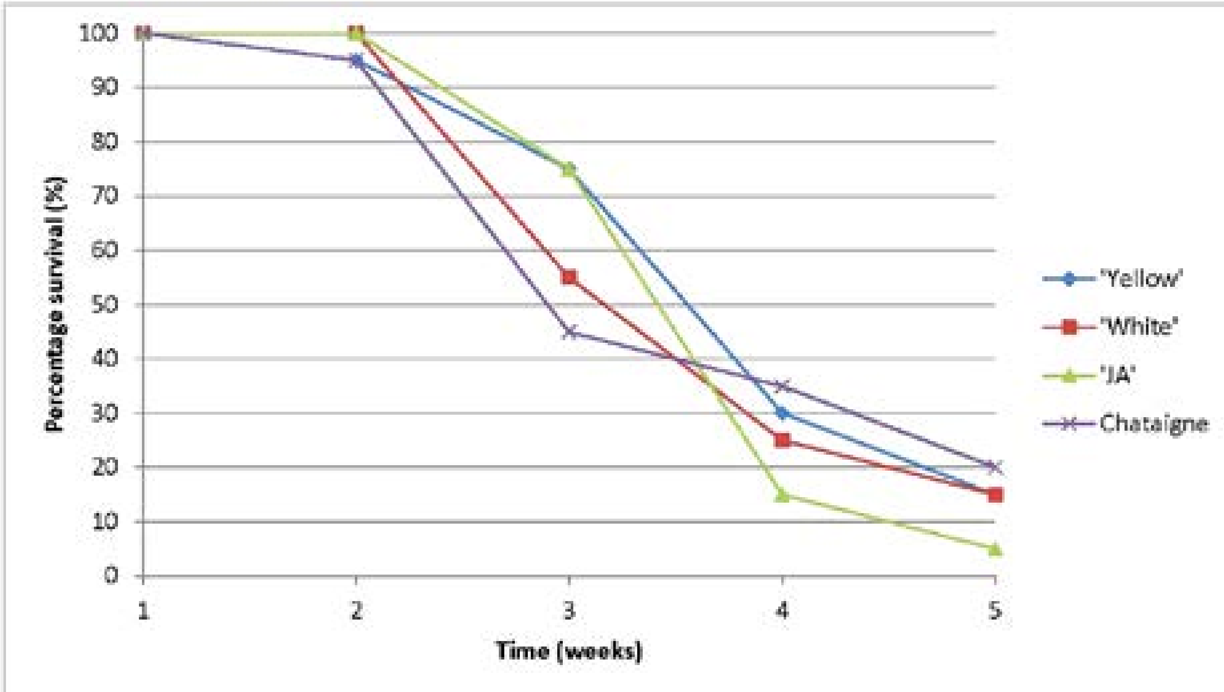


Figure 7: Effect of cultivar on survival percentage of scion over a five week period- Experiment 6.

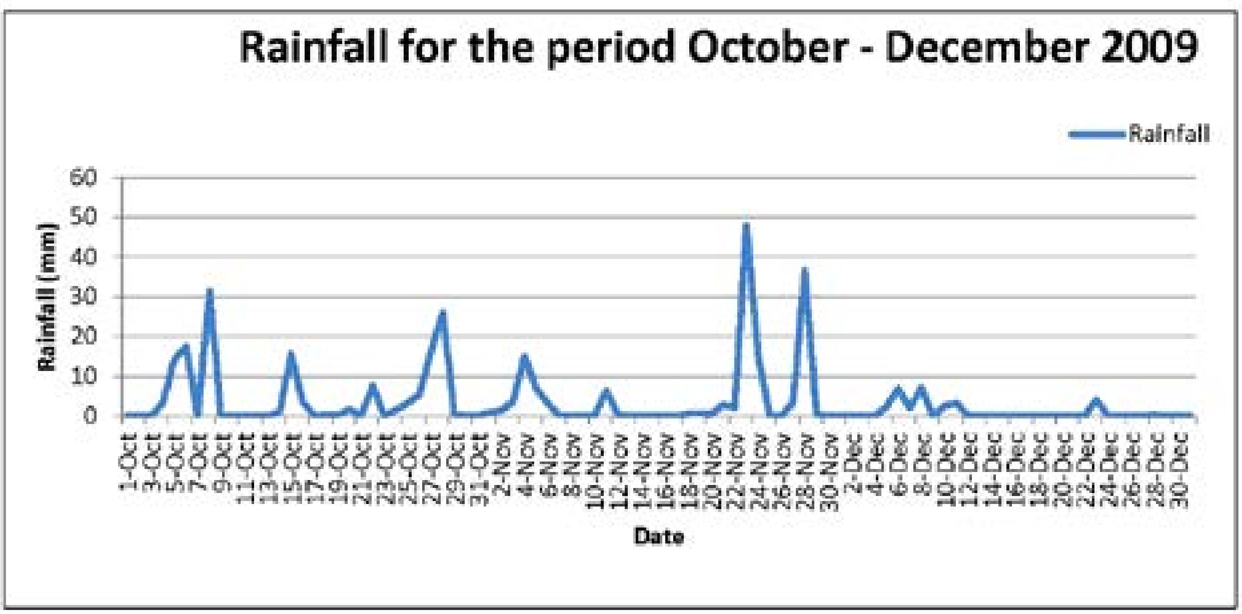


Figure 8: Rainfall pattern for a three month period prior to collecting scion material for Experiment 5 from parent source plants.

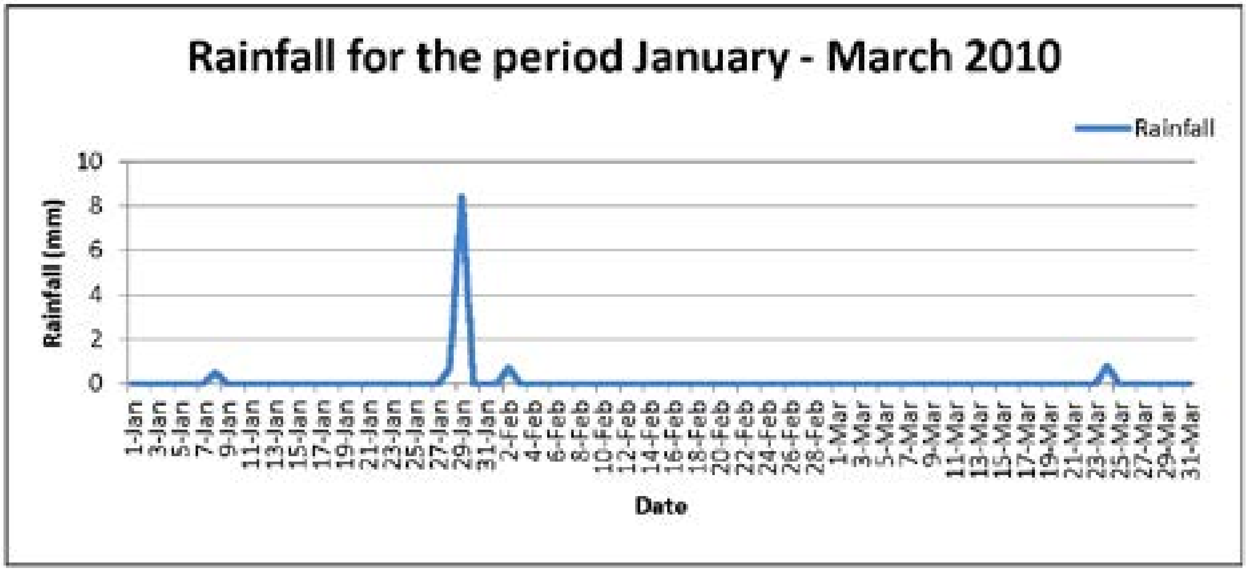


Figure 9: Rainfall patterns for a three month period prior to collecting scion material for experiment 6 from parent source plants.

In the three months leading up to the collection of scion material for the Experiment 5 rainfall was fairly well distributed (Fig. 8). However, scion source parent plants experienced a major drought during the three months prior to collection for Experiment 6, with a total rainfall of 8 mm (Fig. 9). Furthermore, the results of Experiments 5 and 6 showed there was a significant ($p < 0.05$) effect of season on the length of survival of the grafted scion (Table 4).

Discussion

Although, grafting these two species was expected to be highly successful, variable levels of success, ranging from 0 to 83% have been reported (Rowe-Dutton 1976, 253; Galang and Elayda 1924, 204; Padolina 1931, 350; Medagoda and Chandrarathna 2007, 149). This study yielded variable grafting success of 5% to 97%, similar to previous reports. Apparently, these results were characteristic of this genus since reports on grafting success of Jackfruit and *Artocarpus lakoocha* ranged from 2.35% to 75%. Several factors were identified with grafting Jackfruit and *A. lakoocha*. Likewise, the results of the present study indicate that successful grafting of these two species was attributable to several factors.

Grafting method

There have been no reports on evaluation of grafting techniques for breadfruit and chataigne grafting. A basic requirement for a successful graft union is that the cambia of the stock and scion should be in close proximity for interlocking of the parenchyma cells produced from these tissues and for early vascular connection (Hartmann et al. 2011, 462). Therefore, the selection of a grafting method would depend on the rootstock and scion diameter that allow close matching of the cambium regions. Since the diameters of the rootstock and scion increase with age, the choice of the grafting method can be determined by the age of these materials.

Nandwani and Kuniyuki (2005, 308) reported 80% success using approach grafting of one-year old plants but this method would rely on traditional propagation methods to generate entire plants to be used as scion material. This would encounter problems previously stated. Furthermore, because of the plant size at which grafting is done, the method is cumbersome and uses much space which are disadvantages for a commercial planting material production system. Medagoda and Chandrarathna (2007, 149) reported an 83% success rate using the top wedge method on six-week old chataigne rootstocks.

Whip and tongue and top wedge grafting methods are usually used with scion and stock diameters of 6 to 13 mm, while for spliced side grafting a slightly larger diameter range of 6 – 19 mm can be used (Hartmann et al. 2011, 464). The scion and rootstock diameter ranges used in this study for whip and tongue and top wedge grafting were 5.5mm to 9mm and 5.4mm to 14mm, respectively. No significant difference among the grafting techniques were observed possibly because where the diameters of the scion and the rootstock were mismatched, the periderms of both materials were lined up to facilitate close placement of the vascular cambia of both stock and scion, as described in Experiment 1 of this study. In this technique, the union might have been compromised in those regions where the cambium of both stock and scion are not aligned. This may partially explain the short-lived grafts in Experiment 1 after initial indications of successful union. Andrews and Marquez (1993, 200) found that grafts using this technique could eventually display delayed incompatibility.

Age of Rootstock

Medagoda and Chandrarathna (2007, 151) reported only 45% and 25% successful grafting when breadfruit was grafted on 30-day old and 60-day old chataigne rootstocks, respectively compared with 83% success on 45-day old rootstocks and suggested that the significant differences were due to the relative maturity of the rootstocks. However, the results of this present study, with rootstock ages at the time of grafting ranging from 42 to 126 days, did not indicate that this factor significantly influenced successful grafting of these two species. It showed that an average success rate of 51 % could be achieved on the range of rootstock ages that was used.

Nandwani and Kuniyuki (2005, 308) obtained a success rate of 80% with 1-year old breadfruit rootstock and scion materials of different cultivars but did not evaluate the effect of rootstock age. Some studies on grafting jackfruit cultivars showed that the success rate declined as root stock age increased (Aralikatti 2005, 26; Mannan et al. 2006, 77). The variable responses of breadfruit and chataigne grafting to rootstock age may be influenced by other factors. Hartmann et al. (2011, 429) state that scion cultivar, physiology of stock and scion, season of grafting or a combination of these are other factors that determine grafting success.

Cultivar

Variable levels of grafting success were achieved in Experiments 2 to 6 in response to the scion genotype. The overall success rates were highest for chataigne and 'White' breadfruit, intermediate for 'JA1' and lowest for 'Yellow' breadfruit. The high percentage success with chataigne scions was expected because of the genotypic similarity with the rootstock and where success rates were low, other factors discussed above, such as season of scion collection and grafting, maturity of the scion wood and the post-grafting environment, either singly or in combination, were more influential than genotype. Differences in success rates among breadfruit cultivars also strongly suggest genotypic differences in the ability to tolerate less than ideal requirements for these other factors. The longevity of the graft unions and high level of long-term survival of grafted plants (> 90 %) obtained in Experiment 5 clearly demonstrated that high levels of success can be achieved by all breadfruit cultivars evaluated in this study.

Season of grafting

The time of year when jackfruit was grafted was found to be significant. In India, Selvi et al. (2008, 342) reported October was the best month for grafting jackfruit, while Kelaskar et al. (1993, 113) reported that February was the best. The former study corresponded with the rainy season. In this study there were also clear seasonal effects on the rate of success of breadfruit on chataigne stock with the longest survival achieved when scion material was collected and grafted during the wet season of Experiments 2 and 5 (Tables 2 and 4) than during the dry season of Experiments 4 and 6 (Tables 3 and 4). Selvi et al. (2008, 342) found a positive correlation between relative humidity and the grafting success rate in jackfruit and attributed these results to the presence of higher levels of endogenous hormones in the scion that promoted grafting at this time of year.

The season of scion collection and grafting apparently affected the physiological status and morphology of the scion in this study. The scion wood was greener and elongated more rapidly during the wet season, whereas elongation was slower and thicker and lignified stems developed earlier in the dry season. Experiment 2 and the study by Medagoda and Chandrarathna (2007, 150) demonstrated that scion wood from mature breadfruit trees could be grafted successfully if harvested when the trees were exhibiting only vegetative growth after bearing. It can be suggested that scion material collected from parent plants in a vegetative state would have adequate supply storage of carbohydrates, since there are no competing sinks. The importance of the quality of the scion material in terms of its physiological status is indicated further by the difference between Experiment 2 and Experiment 5 in the percentage of successful grafts that survived the hardening period. Scion material was taken from mature trees in Experiment 2 where the average percentage survival was 51% (Fig. 1), whereas with scion from juvenile suckers in Experiment 5, more than 80% (Fig. 6) of the grafts survived in the long-term. Although, similar scion sources were used in Experiments 5 and 6, the duration of graft survival and ultimately, the success rate were significantly lower in the latter experiment, which emphasised the importance of the season of scion collection even from juvenile plants.

Scion quality

In the context of this study the quality of the scion material referred to its suitability in terms of its apparent morphological and physiological status, or both, for use in achieving a good quality graft union. While this factor was not evaluated directly, it appeared to emerge as an important factor in determining successful grafting in breadfruit and chataigne.

There were two types of breadfruit scion material used, which were epicormic shoots from mature trees and axillary shoots from juvenile plants and both achieved high rates of grafting success (Tables 2 and 4), respectively. However, there was a difference between Experiment 2 and Experiment 5 in the percentage of successful grafts that survived the hardening period. This might be explained by the use of scion material collected from mature trees, which had thicker diameters than the rootstock. Additionally, using this type of scion material might have contributed to the toppling and eventual death, stated previously.

On the other hand, the scion material collected from juvenile plants produced shoots that were similar in diameter to the rootstock. Therefore, it could be suggested that the quality of the scion is a factor that influences grafting success, since mismatched scion and rootstock graft unions can lead to incompatibility (Andrews and Marquez 1993, 195). This was observed in Experiment 2. Furthermore, the manipulation for and collection of scion material from mature trees is not sustainable, since this type of material is sourced from the lower branches and, therefore, the quantities needed cannot be supplied in a commercial type propagation system.

Post-grafting environment

Post-grafting environment was another factor that was not evaluated directly; however, it appeared to emerge as an important factor. Bose et al. (1986, 366) and Hartmann et al. (2011, 430) both stated that optimum temperatures between 26 and 29°C and relative humidity above 80% were favourable for the graft union healing process. In Experiments 2, 3 and 4 of this study, an average midday temperature of 29°C was observed in the post-graft environment, while a mean temperature of 24°C was observed for Experiments 5 and 6. Among these experiments, varying levels of successful grafting were achieved, with low reported success in Experiments 3 and 4 (Table 3) and high success in Experiments 2 and 5. These varying results could be explained by the manner in which the RH of the grafted plants were maintained. Although RH was high for the grafted scion in all experiments, the RH of the stock was not maintained in Experiments 3 and 4 when compared with those of Experiments 2 and 5, where RH was maintained for the entire grafted plants. This observation indicates that RH of the entire grafted plant is an important factor in grafting breadfruit on chataigne stock. This is further emphasised by the observation of grafted plants of Experiment 4 that were placed in a propagation bin for the purpose of increasing RH of the entire grafted plant. Due to malfunctioning of the intermittent misting system that caused drying out of the stock and medium, success rate was low.

On the other hand, the results of Experiment 6 of this study showed that even though RH of the entire grafted plant was maintained above 95%, low grafting success was achieved (Table 4). This could be explained by poor quality scion (thicker diameter indicative of slower growth) which resulted from the usually dry period during scion development prior collection (Fig. 9). Hence, the results of these experiments show that in addition to the post-grafting conditions of temperature

(24°C to 29°C) and RH (above 90%) suitable quality scion material was also important.

Conclusion

This study demonstrated that attempts at grafting breadfruit scion on chataigne rootstock could produce variable success rates because several key factors were involved. Rootstocks of any age ranging from 7 to 19 weeks old and any of the grafting techniques evaluated might be used successfully; however, due to its relative ease, the top wedge method might be preferred. The season of scion collection was a very significant factor influencing grafting success because, in addition to the maturity of the scion wood, it affected the quality of the scion in terms of rate of elongation, lignification of the stem, stem diameter and endogenous growth regulators. High levels of grafting success were obtained with all breadfruit cultivars grafted on chataigne but differences among cultivars might reflect differing levels of requirement for scion quality and the post-harvest environment. Although, not directly evaluated, post-grafting conditions for the entire plant of very high relative humidity, with high shade and moderately high diurnal temperatures may be most suitable. Therefore, the recommended protocol for grafting the selected breadfruit cultivars on chataigne rootstock will require using suitable quality scion material, harvested from juvenile mother plants, during wet season, matched with stock of similar diameter and post grafting environmental conditions of 24°C to 29°C and RH above 90% to minimize water loss from both stock and scion.

References

Andrews, Preston, and Carlos Marquez. 1993. "Graft Incompatibility." *Horticultural Reviews* 15 (5): 183 – 232.

Aralikatti, Gangamma. 2005. "Softwood Grafting and In-vitro Propagation Studies in Jackfruit (*Artocarpus heterophyllus*)." Master's in Science thesis. The University of Agricultural Sciences, Dharwad.

Bose, T.K., S.K. Mitra, and M.K. Sadhu. 1986. Propagation of Tropical and Subtropical Horticultural Crops. Calcutta: Naya Prokash.

Coates-Beckford, Phyllis, and Marlene Pereira. 1992. "Survey of Root-inhabiting Microorganisms on Declining and Non-declining Breadfruit (*Artocarpus altilis*) in Jamaica." *Nematropica 22* (1): 55 – 63.

El-Zaher, Abd. 2008. "Using the Grafting for Propagation of the Jackfruit and Producing the Rootstocks for the Grafting." *Agriculture and Environmental Science* 3 (3): 459 – 473.

Galang, F.G., and A.R. Elayda. 1924. "Experiments on Vegetative Propagation of Tropical Fruits at the Lamao Experimental Station, Lamao, Bataan." *Phillipine Agricultural Review* 17: 203-205.

Graham, Horace, and Edna Negron de Bravo. 1981. "Composition of the Breadfruit." *Journal of Food Science* 46: 535-539.

Hartmann, Hudson, Dale Kester, Fred Davies Jr., and Robert Geneve. 2011. Plant Propagation: Principles and Practices. 8th ed. New Jersey: Prentice-Hall, Englewood Cliffs.

Hodges, Charley and Joaquin Tenorio. 1984. "Root Disease of Delonix Regia and Associated Tree Species in the Mariana Island caused by Phellinus noxius." *Plant Disease* 68 (4): 334-335.

Islam, M.M., M.A. Haque, and M.M. Hossain. 2003. "Effect of Age of Rootstock and Time of Grafting on Success of Epicotyl Grafting in Jackfruit." *Asian Journal of Plant Science* 2 (14): 1047 – 105.

Jones, Andrew. 2010. "Investigation into Morphological, Agronomic and Nutrition Diversity within Breadfruit (*Artocarpus*, Moraceae) as a Resource for Food Security." PhD thesis. The University of British Columbia, Okanagan.

Kelaskar, A.J., A.G. Desai, and M.J. Salvi. 1991."Effect of Rootstock, Leaf Retention, Shade and Tying Material on Patch Bud Grafts of Jackfruit." *Indian Journal of Plant Physiol* 34 (1): 58 – 62.

Kelaskar, A.J., A.G. Desai, and M.J. Salvi.1993. "Effect of Season on the Success and Growth of Bud Grafts of Jack (*Artocarpus heterophyllus* Lam.)." *Journal of Tropical Agriculture* 31: 112 – 115.

Mannan, M.A., M.M. Islam, and S.A.Khan. 2006. "Effects of Methods of Grafting and Age of Rootstock on Propagation of Off-Season Germplasms of Jackfruit." *Khulan University Studies* 7 (2): 77 – 82.

Medagoda, Indrani, and Kumara Chandrarathna. 2007. "Grafting of Breadfruit (*Artocarpus altilis*) Using Breadnut (*Artocarpus camansi*) as Rootstock." *Acta Horticulturae (ISHS)* 757: 149-152.

Nandwani, Dilip, and Andrew Kuniyuki 2005. "Grafting and Improvement of Breadfruit Production in Micronesia." *Acta Horticulturae (ISHS)* 694: 307-310.

Padolina, Felipe. 1931. "Vegetative Propagation Experiments and Seed Germination." *Philippne Journal of Agriculture* 2 (4): 347-363.

Ragone Diane. 2001. "Chromosome Numbers and Pollen Stainability of Three Species of Pacific Island Breadfruit (*Artocarpus*, Moraceae)." *American Journal of Botany* 88 (4): 693-696.

Roberts-Nkrumah, Laura. (Lecturer, Department of Food Production, UWI, Trinidad and Tobago). 2011. Interview by 1st author, October 10. St Augustine, Trinidad and Tobago.

Roberts-Nkrumah, Laura. 1993. "Commercial Plant Propagation Techniques for Breadfruit."*JAGRIST*4 (2): 24-25

Roberts-Nkrumah, Laura.1998. A Preliminary Evaluation of the Imported Breadfruit Germplasm Collection at the University of the West Indies, Trinidad. "Proceedings of the 34th Caribbean Food Crops Society, 12 – 18 July 1998, 29-34. Montego Bay, Jamaica.

Rowe-Dutton, Patricia. 1976. "Breadfruit." In The Propagation of Tropical Fruit Trees, edited by R.J. Garner and S.A. Chandri, 248 – 266. London: CABI publishing.

Selvi, R., N. Kumar, M. Selvarajan, and S. Anbu. 2008. "Effect of Environment on Softwood Grafting Success in Jackfruit." *Indian Journal of Horticulture* 65 (3): 341 – 343.

Sharma, K. and S. Thakur. 2005. "Vegetative Multiplication of *Artocarpus lakoocha*- A hard to Root Species." *Indian Forester* 131: 259 – 260.

Trujillo, E. 1971. The breadfruit Diseases of the Pacific Basin. Caledonia: South Pacific Commission Noumea.

Webster, Seymour. 2006. The breadfruit in Jamaica: A Commercial and Horticultural Perspective. Jamaica: Webster.

Weir, Colin, Egbert Tai, and Cynthia Weir. 1991. Fruit Tree Crop Production in the Caribbean Region. Trinidad: Weir's agricultural consulting services.

Wickham Lynda. 2001. Small Scale Processing of Starchy Staples in CARICOM Countries. UN: Food and Agriculture Organisation.

Zaiger, D., and G.A. Zentmyer. 1966. "A New Lethal Disease of Breadfruit in the Pacific Islands." *Plant Disease reporter* 50(12): 893-897.

Zerega, Nyree, Diane Ragone, and Timothy Motley. 2004. "Complex Origin of Breadfruit (Artocarpus altilis, Moraceae): Implication for human Migration." *Amercian Journal of Botany* 9 (5): 760 – 766.

SPECIAL ISSUE IN COMMEMORATION OF AGRICULTURAL LEGACY THROUGH TEACHING, RESEARCH AND INNOVATION
Extracted from Volume 96, 2019

Successful manipulation of the growth cycle of yam (*Dioscorea* spp.) for year-round production for food security and climate change

Lynda D. Wickham

Department of Food Production, Faculty of Food and Agriculture,
The University of the West Indies St. Augustine, Trinidadand Tobago, W.I.

Corresponding author email.- lynda.wickham@sta.uwi.edu

Yams are important items of diet throughout the Caribbean Region and, among them, the cultivars of the species, *Dioscorea alata* L. and *D. esculenta* (Lour.) Burkill are particularly important in the Eastern and Southern Caribbean, although the latter is so to a lesser extent. With a growing period of approximately nine months and a corresponding dormancy period, these cultivars are produced on an annual basis like clockwork, providing food yams for approximately three months of the year, the period of availability coinciding with the period of dormancy as the latter marks the natural period of storage of the tuber. Consequently, the breakage of dormancy marks the beginning of the end of natural storage as the emerging sprouts signal the onset of the next growing period. This coincides with the start of the rainy season and the yam is adapted to existing climatic conditions that provide the ideal environment for both plant establishment and tuber growth.

Cultivars of the two species bear no reproductive seed and therefore, are completely dependent on vegetative means for perpetuation. Any adverse development during storage or early growth that prevents sprouting or tuber initiation and growth, results in the permanent loss of the affected material and potentially threatens loss of the specific cultivar. Hence, climate change events such as shifts in the onset of the rainy season, extension of the dry period and incidences of severe weather associated with excessive flooding that can result in death of roots and developing tubers, pose real risks to the persistence of the cultivars of *D. alata* and *D. esculenta* that are produced in the Caribbean Region. In order to counteract these effects, what is needed is the manipulation of the growth cycle to allow for year-round production so that the changes that have been observed with respect to climatic and weather patterns will not result in a loss of planting material and, by extension, loss of germplasm.

It is well-established that the growth cycle is under hormonal control and that the key to year-round production is the breaking of the physiological lock on the growth cycle that is responsible for the seasonal production by which these species are characterized. There have been many attempts by researchers in the past to achieve this, but without success until relatively recently. Most attempts have explored the use of natural and synthetic plant growth regulators. Further, past attempts have focussed on the breakage of natural dormancy and induction of early sprouting, but instead, the success reported here, was achieved by delaying sprouting to beyond the period of natural dormancy in a novel approach that eliminates the use of growth regulators and other chemicals.

This paper reports how reduced temperature storage has been used successfully to break the physiologically controlled growth cycle in cultivars of *D. alata* and *D. esculenta*, producing yams all year long by delaying the breakage of dormancy, ensuring not only an extension of the availability of yam tubers for food but also availability of viable planting material throughout the year. It was found that tubers can be stored successfully for an entire cycle, so that tubers from the previous year can meet tubers of the current year's harvest providing a buffer against crop loss from any adverse biotic or climatic event. The effects on sprouting patterns are described. The use of reduced temperature storage for this purpose has not been reported and this account serves to fill an important gap in documented yam dormancy research.

Keywords: Yam, *Dioscorea* spp., growth cycle, year-round production, food security, climate change, reduced temperature storage

0041-3216/2021/030326-336

The value of the yam tuber for food is inherent in ethnic and cultural practice as well as in its physiological dormancy that facilitates its natural storage period and the relatively long postharvest life for tubers of some species and cultivars (Coursey 1967; Degras 1993).

Yams are important items of diet throughout the Caribbean Region and, among them, the cultivars of *Dioscorea alata* L. and *D. esculenta* (Lour.) Burkill are particularly important in the Eastern and Southern Caribbean, although the latter is so to a lesser extent (Wickham 1981). With a growing period of approximately nine months and ten months, for *D. alata* and *D. esculenta*, respectively, and a corresponding dormancy period of about three months and two months, respectively, these cultivars are produced on annual basis like clockwork, providing food yams for approximately three months of the year, the period of availability coinciding with the period of dormancy as the latter marks the natural period of storage of the tuber. It was established long ago that tubers planted early remained dormant in the ground despite favourable growing conditions and that tubers sprouted after a pre-set period of time regardless of the planting environment (Onwueme 1975; 1976; Passam et al. 1982). Consequently, the breakage of dormancy marks the beginning of the end of natural storage as the emerging sprouts signal the onset of the next growing period. The onset of the growing period coincides with the start of the rainy season and the yam is adapted to existing climatic conditions that provide the ideal environment for both plant establishment and tuber growth at the required time. Accordingly, yams are characterized by a cyclic pattern of growth, making them seasonally available for food and making the prospect of year-round availability through extension of dormancy or year-round production, a much sort after goal.

Cultivars of the two species bear no reproductive seed and therefore, are completely dependent on vegetative means for the perpetuation of the species. Any adverse development during storage or early growth that prevents sprouting or tuber initiation and growth, results in the permanent loss of the affected material and threatens permanent loss of the specific cultivar as well. Hence, climate change poses a real risk to the persistence of the cultivars of *D. alata* and *D. esculenta* that are produced in the Caribbean Region.The threat of climate change has heightened the awareness of the potential for negative impact on the yam as a food crop, the four major ones being:

- Anthracnose (leaf spot disease) incidence early in the growth cycle killing plants before tuber initiation or before they form viable tubers. It is noteworthy that cultivars of *D. esculenta* are resistant to anthracnose.
- Proliferation of pests like nematodes and mealy bugs during prolonged storage as occurs when rains are late. Such pests destroy the tuber germination meristem, the area where adventitious shoots and roots are produced *de novo*.
- Extremes of soil water availability that can lead to complete crop loss as in the case of permanent wilting of newly-established plants or death of roots and newly-formed tubers by flooding, destroying not only yield, but the possibility of future crops.
- Shifts in the dry and wet seasons (that have been observed already with very negative consequences), resulting in such hazards as pest and disease proliferation, bush fires, loss of planting setts/poor plant establishment related to unavailability of water at critical times in the growth cycle.

In order to mitigate potential negative climatic changes, achieving sustainable production must be the goal. What is needed is the manipulation of the growth cycle to allow for year-round production so that the changes that have been observed with respect to climatic and weather patterns will not result in a loss of planting material and, by extension, loss of the genetic material, because, at any given time, plants and tubers will be available at the various stages of development eliminating the risk of total loss.

However, the production of these yams is never assured and is threatened by factors including, for susceptible species like *D. alata*, the incidence of the leaf spot disease, anthracnose, caused by *Colletotrichum geosporoides*. Anthracnose is unique in that its strong tendency to mutation to produce new strains makes treatment and management of the disease difficult. For the same reason, yam breeding programmes for the development of anthracnose-tolerant species also yield short-term success as tolerant types succumb to new strains. *D. esculenta* is resistant to anthracnose (Wickham 1981).

Typically, *D. alata* cultivars are adapted to the environmental conditions of the area where they are found with the adaptation often associated with the availability of ground water resulting from precipitation. The conditions that are ideal for yam growth are also favourable for the proliferation of the anthracnose organism. Further, yam tuber formation does not begin until three to four months after planting/ breakage of dormancy. The end result of all this is the constant threat of loss of yam germplasm as a result of this disease. Achieving year-round production will also reduce this threat.

It has been known for decades, that reduced temperature storage above chilling temperatures can delay the breakage of dormancy in yams to varying extents, depending on the period of storage and the temperature used (Coursey 1968). Also, the use of the naturally-occurring growth regulator, gibberellic acid, has been demonstrated to have great efficacy in delaying the breakage of dormancy, or rather, in extending the length of the dormant period in yams after harvest (Okagami and Nagao 1971; Wickham 1981; Wickham et al. 1984). However, both methods have not been used commercially to any extent, the latter because of tradition and the lack of dissemination of information for adoption of the technology, and the former, because of the cost of energy for reduced temperature storage maintenance on an extremely valuable, but low-priced crop.

Given the relatively long growth period, of approximately nine months, and its seasonal availability as a result of its dormancy, the natural reasoning is to go for an extended period of dormancy to allow for year-round production, and thus, year-round availability through manipulation of the period of dormancy, and through it, the period of growth. It is well-established that the growth cycle is under hormonal control and that the key to year-round production is the breaking of the physiological lock on the growth cycle that is responsible for the seasonal production by which these species are characterized. There have been many attempts by researchers in the past to achieve this (Wickham 1981; Wickham et al. 1984; Ireland and Passam 1985; Barker et al. 1999; Craufurd et al. 2001; Ile et al. 2006) but without the expected effect on the growth cycle. Even when natural compounds were used such as reported by Tortoe et al. (2015) using plant extracts from cocoa pod (*Theobroma cacao*) potash, neem (*Azachirata indica*) seeds, neem leaves, sweet potato (Ipomoea batatas) leaves to inhibit bud and sprout formation, emphasis was on prolonging dormancy and not on manipulation of the growth cycle.

Given the effect of gibberellic acid, its use to bring about year-round production in yams was explored and found to be not feasible. It was found that while exogenous applications of GA3 resulted in extension of the dormant period and that repeated applications resulted in further extensions, the treatment resulted in eventual direct sprouting-tuber to developing-tuber transfer of assimilates through the primary nodal complex (Ferguson 1972; Wilson et al. 1998) without the institution of obvious shoot growth (Wickham 1981; Wickham et al. 1984), and with no effect on the growth cycle. The unique association between the harvest date and the time of sprouting was also reported later by several researchers including Swannell et al. (2003) and Ile et al. (2006) who found that the date of harvest had no effect on the time to 50% sprouting and Ile (2004) had earlier hypothesized that yam tubers are only receptive to plant growth regulators applied near their natural sprouting time, i.e., the observed effect was on the rate of shoot development and not on tuber dormancy.

With the goal of achieving sustainable year-round production of yams still elusive, more recent studies have demonstrated the induction of sprouting in dormant yam tubers with the use of gibberellin inhibitors (Shiwachi et al. 2003), and use of propriety products, CF1 and CF2, to break the dormancy of 10 g slices of freshly harvested tubers (*D. alata*) reducing the pressure on the use of ware tubers as propagules (Acedo and Arradaza 2013). The efficacy of Fluridone, an inhibitor of abscisic acid (ABA) synthesis, in inducing sprouting in dormant yam (*D. alata*) tubers, as well as immature tubers shortly after tuber initiation has also been reported (Somina and Hamadina 2018).

On the other hand, while the efficacy of reduced temperature storage for extension of the shelf life and availability of yams for food is well known (Barker et al. 1999), although not a common practice, its use to extend tuber storage life under controlled conditions, generally, has not been explored beyond production for off-season availability (Gonzalez and Collazo de Rivera 1972; Rao and Calixte 1990). This is probably because of the relatively high cost of reduced temperature maintenance. Research investigations with respect to manipulations of dormancy and sprouting, using higher temperatures, have also been conducted and reviewed (Barker et al. 1999; Craufurd et al. 2001), but without yielding results significant to year-round production.

The objective of this investigation was to determine the effects of reduced temperature storage on the dormancy, subsequent sprouting and the growth cycle of cultivars of *D. alata* and *D. esculenta* and to observe the effects of storage of *D. alata* tubers from one growth cycle to the next, i.e., for up to one year and beyond.

Materials and methods

Observations of the effects of reduced temperature storage at 15°C on dormancy, sprouting and subsequent growth of yam (*D. alata* and *D. esculenta*) tubers were made over a period of eight years, from 2011 to 2019.

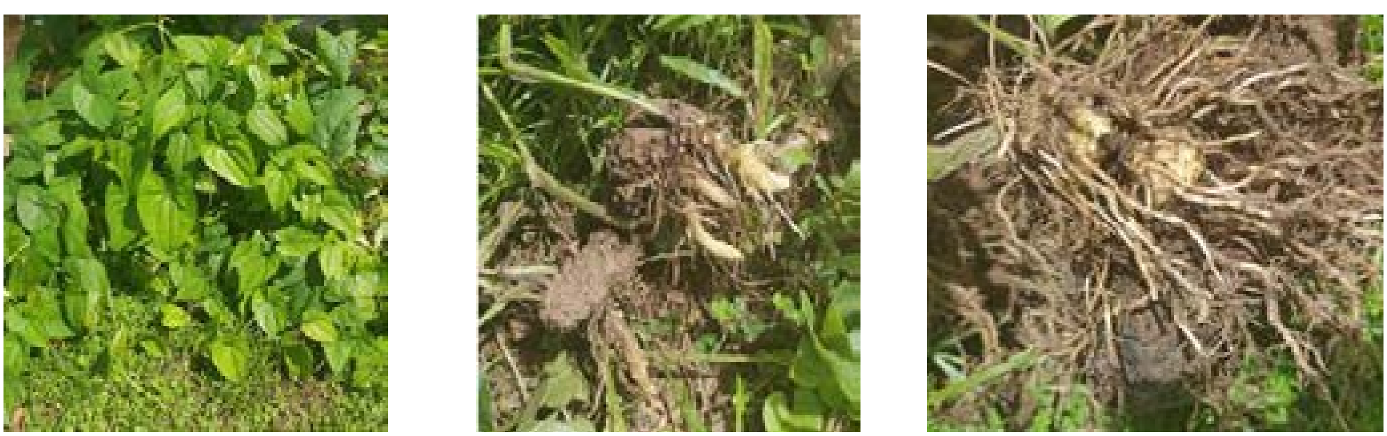
On an annual basis, freshly-harvested dormant tubers were placed in storage at 15°C and 90% relative humidity (supplemented with wetting of the floor of the storage room and light cardboard covers to keep moisture loss from the tubers at a minimum). Tubers were stored for the duration of natural dormancy and for up to 12 months and beyond. Yams from the same harvest, stored under normal tropical ambient conditions, were used as the control. After natural dormancy was broken in the control tubers, stored tubers were removed at intervals and placed under tropical ambient conditions for continued observations. Tubers were examined for the production of sprouts during and after removal from storage. Following removal from storage to tropical ambient conditions, tubers were left to sprout, unplanted, either in a ventilated storage room, or in a moist natural environment to observe the time to tuber initiation and early tuber development. Selected tubers were prepared as planting setts or were planted in containers for observation on the length of the growth cycle, or were planted in beds in the field and observed for growth patterns, length of the growing period, onset of senescence/dormancy, length of dormancy and subsequent sprouting of daughter tubers. Irrigation was supplied as necessary for plants that were in the active growth phase during the normal dry season, i.e. plants that were demonstrating out-of-season production.

Plants established from stored tubers were left unharvested and allowed to sprout, grow, senesce, go through a subsequent dormant period and sprout again to confirm the growth cycle in the prevailing natural environment. Water was supplied to ensure the survival of plants that were growing off-season.

Results and discussion

As expected, tubers were stored successfully at 15°C (16 ± 1°C) with no symptoms of chilling injury which occurs in yam tubers between 10-12°C (Coursey 1968), and no sprouting occurred in tubers while held at that temperature.

Plate l. Entwined vines of sprouting tubers of *Dioscorea alata* and *D. esculenta* (A) left in a moist environment without burial after removal from reduced temperature storage, show developing tubers (B, C) five months after commencement of sprouting.



A B C

Plate 2. A. Plant of *Dioscorea alata* with extensive vine growth, in tuber bulking phase, September 14, 2018. B. Same plant, showing symptoms of anthracnose infection, in senescence phase, November 07, 2018. This represents a four-month advancement in the normal growth cycle that will allow tubers to sprout in approximately three months providing a crop to be established in mid-February instead of late May. C. Plant of *Dioscorea alata*, established early July, with vigorous vine growth four months after sprouting and in tuber initiation phase, November 07, 2018. This represents a six-week delay in natural crop establishment.

A B C

Plate 3. A. *Dioscorea esculenta* cv. Chinese in advanced stage of sprouting mid-April 2017. Sprouting commenced early March 2017, two months before normal breakage of dormancy. B. *Dioscorea alata* cv. Sweet in early stage of sprouting mid-April 2017. Sprouting commenced early April 2017, five weeks before normal breakage of dormancy.

A B

Plate 4. January 22, 2018, vines of *Dioscorea esculenta* cv. Chinese showing plants existing at completely different phases at the same time: A. Heavy vine growth, tuber bulking phase. B. Early stages of sprouting.

A B

Plate 5. April 19, 2018, vines of *Dioscorea esculenta* cv. Chinese at three different growth stages at the same time. Second generation tubers from tubers allowed to sprout by returning to ambient conditions after storage at l5°C, were left unharvested to observe the natural growth cycle: A. Plant establishment stage, five weeks after sprouting. B. Advanced stage of growth, heavy vine growth seven months after sprouting. C. Senescent vines, nine months after sprouting with senescent vines indicating onset of tuber dormancy.

A B C

It was found that yams could be stored at 15°C, for a period equivalent to the length of natural dormancy, and then returned to ambient conditions at monthly intervals to be released from the induced/extended dormancy in such a way that sprouting tubers could be available every month of the year. Plants established from such tubers underwent a normal growth period, followed by vine senescence, before becoming dormant and sprouting after approximately three and two months respectively for tubers of *D.alata* and *D. esculenta*. In other words, tubers experienced a growth cycle of normal length after sprouting occurred. Thus, this approach resulted in year-round production of tubers.

Observations on the length of the growth cycle of plants from stored tubers of *D. alata* and *D. esculenta*

Sprouting occurred in tubers returned to tropical ambient conditions over a period of four to eight weeks and tuber initiation occurred three to four months after the onset of sprouting, providing plants that senesced, similarly, over a period of time. This pattern facilitated year-round production and by careful selection and selective establishment, the sprouting tubers were used to create plots that yielded tubers throughout the year (Plates 1,2,3,4, and 5).

Effect of reduced temperature storage for one year after harvest on tuber dormancy

It was found that tubers could be stored successfully at 15°C for one year, with freshly harvested dormant tubers meeting tubers stored from the previous crop. Yams were found to sprout normally after removal to ambient conditions following storage at 15°C for one year after harvest. This meant that yams from a previous year's harvest could be sprouted alongside yams from the current year's harvest (Plate 6A). Off-season production from smaller setts yielded smaller tubers with otherwise normal postharvest physiology (Plate 6B).

Effect of prolonged storage on sprouting pattern and proximal end dominance

While normal proximal end dominance was displayed by sprouting tubers after removal to tropical ambient conditions, there was evidence of increasing loss of proximal end dominance, the longer after harvest the tuber was kept. This was progressively more pronounced with prolonged storage in excess of one year, giving rise to a condition in which numerous sprouts arose over the surface of the tuber when dormancy was broken after removal from reduced temperature storage to tropical ambient conditions.

After storage for one year, removal of tubers to ambient conditions resulted in the development of sprouts within four weeks. Tubers kept at ambient conditions without planting, continued to develop sprouts on the tuber surface (Plate 7A). Tubers kept at ambient but under moist conditions developed sprouts all over the tuber surface, demonstrating loss of proximal end dominance, and had excessive root growth and sprout elongation (Plate 7B). When tubers were kept for several weeks under these conditions, without planting, daughter tubers developed as stored material was transferred to the areas of new tuber initiation (Plate 7C). This development was probably as a result of depletion of growth regulators, possibly auxins, that control the location of sprouts after breakage of dormancy and is responsible for the strong proximal end dominance displayed in yam tubers.

The sprouting pattern was characterized by continued sprout development after plant establishment and the emergence of early sprouts. This gave rise to clumps of vines arising from a single planting sett or tuber, as several yam plants developed in close proximity to each other. Each plant produced at least one tuber. The number and shape of the tubers produced were characteristic of the cultivar. However, the tubers were miniature replicates because of the level of competition resulting from multiple vine development from each planting sett (Plate 7D).

From a practical standpoint, this occurrence proved to be very positive as it gave rise to large numbers of shoots and associated tubers, resulting in yield of large numbers of small, generally unmarketable tubers (Plate 7D) that served as planting setts and that went on to perform normally with a growth cycle of normal length. Thus, not only did this storage procedure produce tubers that sprouted at varying times in the year, based on the length of storage at reduced temperature, but it also produced tubers that served as a source of intact planting material, eliminating the need to dissect the tuber into setts, thus reducing the risk of loss of planting material due to microbial infection.

Plate 6. A. Tubers of *Dioscorea alata* cv. Sweet harvested in February 2012 and stored for one year, alongside freshly harvested tubers from crop of February 2013. B. Small tubers from off-season production in 2013 alongside tubers from normal 2013 crop.

A

B

Plate 7: Tubers of *Dioscorea alata*: A. Tuber with loss of proximal end dominance after prolonged storage at reduced temperature. B. Tuber kept moist at tropical ambient conditions, to observe the effect on sprouting pattern after prolonged storage at reduced temperature. Proximal end dominance is eliminated as seen from multiple shoot development all over the tuber surface. C. Tuber kept for several weeks under moist conditions, without planting, showing development of daughter tubers as stored material was transferred from the sprouting stored tuber to the areas of new tuber initiation. D. The approximately 30 tubers shown here, represent the yield from a single planted tuber (planting sett), demonstrating the result of multiple shoot formation, with each shoot producing at least one tuber. Normally, this cultivar produces one or two tubers per planting sett.

A

B

C

D

Plate 8. Strong proximal end dominance displayed in sprouting, miniature tuber of *Dioscorea alata*, one of many tubers resulting from multiple shoot growth from a single planting sett in which proximal end dominance had been lost as a result of prolonged storage under reduced temperature conditions.

It was found that this effect on pattern of sprouting did not extend beyond the current batch of propagules, and yam tubers returned to normal patterns of sprouting and proximal end dominance by the following harvest season. Normal cultivar differences with respect to time to sprouting and rate of sprout development were evident, for example, cv. Lucie was early while cv. Sweet was late. The development of sprouting in the second-generation tubers was characterized by strong proximal end dominance and the yams were re-established in the field in May, the traditional planting month for *D. alata* yams in this area. Therefore, while long-term storage resulted in abnormal sprouting patterns with excessive shoot and tuber development, tubers from plants that arose from such multiple shoots, exhibited normal physiology and strong proximal end dominance (Plate 8).

Conclusion

Propagated only by vegetative means, with a distinct period of vegetative growth followed by a distinct period of dormancy, environmental changes that affect development of the vines and or tuber pose great risk to the sustainability of the production of some species of yam. It has been demonstrated here that yams can be grown year-round as a result of delaying tuber sprouting beyond the period of natural dormancy by the use of reduced temperature (15^{o}C) storage. Tubers can be returned to tropical ambient conditions at controlled intervals for sprouting and plant establishment in order to provide material for year-round production.

Also, these investigations demonstrated that tubers of selected cultivars of *D. alata* can be kept under reduced temperature storage conditions for in excess of twelve months i.e. overlapping of harvests. Planting of this material gave rise to several sprouts per tuber or planting sett and yielded many corresponding small daughter tubers. The tubers from this establishment were dormant at harvest as is common for yams, were morphologically normal, and demonstrated a period of dormancy consistent with the cultivar and sprouted with strong proximal end dominance as is characteristic of *D. alata* yams. Thus, the loss of proximal end dominance is not permanent, lasting only for the current cycle as long as there is no further manipulation of the storage environment.

The implications of this finding is that yam tubers, normally propagated by vegetative means and subject to the risk of loss of the germplasm as a result of various agronomic, biotic and adverse environmental conditions, can be stored from harvest to harvest, with retained sprouting vigour but with reduced proximal end dominance, providing not only preservation of planting material, but also large numbers of viable propagules, eliminating or greatly reducing that risk.

What has been reported here offers real hope for the future with respect to the possible impact of climate change on yam production. Already demonstrated are the sustained shifts in the growing season, so that at any given time it will be possible to have established plants, at all phases of growth, along with dormant tubers (planting material) of the yam species, *Dioscorea alata* and *Dioscorea esculenta*. Thus, achievable, sustainable year-round production has been demonstrated for these two species.

Dedication

This paper is dedicated to the memory of Professor Lawrence A. Wilson who, in 1976, introduced me to the incredible wonder of the physiology of Dioscorea species.

References

Acedo, V.Z. and C.C. Arradaza 2013. "Breaking Yam Tuber Dormancy with Appropriate Chemical Treatment." *Acta Horticulturae* 989:343-346.

Barker D.J., J.D.H. Keatinge, and R. Asiedu. 1999. "Yam Dormancy: Potential Mechanisms for its Manipulation." *Tropical Science* 39 (3): 168–177.

Coursey D.G. 1967. Yams. London: Longmans, Green and Co. Ltd.

Coursey D.G. 1968. "Low Temperature Injury in Yams." *Journal of Food Technology*, 143-150.

Craufurd P.Q., R. J. Summerfield, R. Asiedu, and P.V. Vara Prasad. 2001. "Dormancy in Yams (*Dioscorea* spp.)." *Experimental Agriculture* 37:147–181.

Degras, L. 1993. The Yam: A Tropical Root Crop. Basingstoke, UK: MacMillan Education Limited.

Ferguson T.U. 1972. "The Propagation of *Dioscorea* spp. by Vine Cuttings – A Critical Review." *Tropical Root and Tuber Crops Newsletter* 5: 4-7.

Gonzalez, M.A., and Collazo de Rivera. 1972. "Storage of Fresh Yams (*Dioscorea alata* L.) Under Controlled Conditions." *J. Agric. Univ. Puerto Rico* 56:46-56.

Ile, E I. 2004. "Control of Tuber Dormancy and Flowering in Yam (*Dioscorea rotundata* Poir.) Tuber." PhD thesis, The University of Reading, Reading, UK.

Ile, E.I., P.Q. Craufurd, N.H. Battey, and R. Asiedu. 2006. "Phases of Dormancy in Yam Tubers (*Dioscorea rotundata*)." Ann Bot. 97(4): 497–504.

Ireland, C.R., and H.C. Passam.1985. "Effect of Exogenous Batatasin, Batatasin Analogues and Gibberellins on the Dormancy of Stored Yam Tubers." *Tropical Agriculture* 62:41–46.

Okagami, N. and M. Nagao. 1971. "Gibberellin-Induced Dormancy in Bulbils of Dioscorea." *Planta* 101(1): 91-94.

Onwueme, I.C. 1975. "Influence of Storage Time on Earliness of Sprouting and Tubering in *Dioscorea rotundata* Yams." *The Journal of Agricultural Science (Cambridge)* 84:503-5.

Onwueme, I.C. 1976. "Performance of Yam (*Dioscorea* spp.) Setts Planted Without Water." *The Journal of Agricultural Science (Cambridge)* 87:413-15.

Passam H.C., L.D. Wickham, and L.A. Wilson. 1982. "A Note on the Relationship between Maturity and Dormancy in Tubers of *Dioscorea alata* L." *Tropical Science* 24:47–51.

Rao, M.M., and C. George. 1990. "Studies to Extend the Dormancy of White Yam (*Dioscorea alata* L.)." *Journal of Agriculture. University of Puerto Rico* 74(3): 213-219.

Shiwachi, H., T. Ayankanmi, R. Asiedu, and M. Onjo. 2003. "Induction of Germination in Dormant Yam (*Dioscorea* spp.) Tubers with Inhibitors of Gibberellins." *Experimental Agriculture* 39:209–217.

Somina, B., and E.I. Hamadina. 2018. "A Role of Abscisic Acid in the Induction of Tuber Dormancy in Yam (*Dioscorea alata* L.)." *Advances in Life Sciences* 8(1): 32-38.

Swannell, M.C., T.R. Wheeler, R. Asiedu, and P.Q. Craufurd. 2003. "Effect of Harvest Date on the Dormancy Period of Yam (*Dioscorea rotundata*)." *Tropical Science* 43:103–107.

Tortoe, C., S. Dowuona, and N.T. Dziedzoave. 2015. "Determination of Sprout Control Treatment Using Seven Key Yam (*Dioscorea* spp.) Varieties of Farmers in Ghana." *World Journal of Agricultural Research* 3(1): 20-23. doi: 10.12691/wjar-3-1-5.

Wickham, L.D. 1981. "The Extension of Dormancy in Tropical Yams." Ph.D. Thesis, The University of the West Indies, St. Augustine, Trinidad and Tobago.

Wickham L.D., H.C. Passam, and L.A. Wilson. 1984. "Dormancy Responses to Post-Harvest Application of Growth Regulators in *Dioscorea* Species. 2. Dormancy Responses in Ware Tubers of D. alata and D. esculenta." *Journal of Agricultural Science* 102:433–436.

Wilson L.A., L.D. Wickham, and T. Ferguson. 1998. "Alternative Manifestations in Origin, Form and Function of the Primary Nodal Complex of Yams (*Dioscorea* spp.): A Review." *Tropical Agriculture (Trinidad)* 75:77–83.

Authors' Guidelines

Please read and follow these instructions carefully to ensure that the publication of your manuscript is not delayed. The Publisher reserves the right to return manuscripts that are not prepared in accordance with these instructions.

Manuscript format:
The paper should include – Title of paper, Authors names and affiliation, Contact information including e-mail address, Abstract, Keywords, Introduction, Materials and Methods, Results, Discussion, References, and Tables, Figures and Illustrations.

Research Papers: A research paper should be written concisely not exceeding 6000 words in length, with double line spacing, typed on one side of the page. All lines should be numbered.

Research Notes: A research note is not a full academic paper, it serves to advance a new idea, theoretical perspective, or methodological approach in a scientific study. A research note should be written concisely not exceeding 3000 words in length, with double line spacing, typed on one side of the page. All lines should be numbered.

Review Papers: A review paper summarizes the current state of understanding of a topic. It surveys and summarizes previously published studies, rather than reporting new facts or analysis. A review paper should be written concisely not exceeding 6000 words in length, with double line spacing, typed on one side of the page. All lines should be numbered.

Submission:
Manuscripts should be submitted in English using the journal's website. Authors need to register on the website before they can submit a paper. The URL is

http: //journals.sta.uwi.edu/ta/index.asp? action=authors.

Tables, figures, illustrations and photographs must be submitted on separate pages. If you have difficulty in submitting your paper, please email your paper as an attached file to tropical.agri@sta.uwi.edu.

Tables, Figures and Photographs:
All graphs and figures should be prepared in programmes compatible with Microsoft word for Windows operating systems. Both plotted graphs and figures and their co-ordinates should be submitted. Each category of graphics should be numbered consecutively with Arabic numerals. Footnotes to tables should be indicated by lower-case superscript letters.

Figures should be limited to those essential for the text. A result should not be duplicated by presentation as both a table and a graph.

Legends must be brief, self-sufficient explanations of the figures and tables. When symbols, arrows, numbers or letters are used to identify parts of an illustration, identify and explain each one clearly.

Line drawings should be submitted as clear black and white drawings suitable for reproduction. All lines should be of uniform thickness. Figures should allow for same-size reproduction and no larger than 20.2 by 25.4cm.

Micrographs should carry an internal measurement, the value of which should be stated in the accompanying legend.

Units and Abbreviations:
Units of measurement must conform to the SI system. Abbreviations and symbols should conform to conventions of the IUPAC-IUB Commission.

Statistics:
Appropriate statistical tools used for data analysis should be identified and proper references provided.

Citations and References:
These should be in accordance with Chicago manual of Style, 16th Edition. References should be arranged alphabetically by first author surname, initials and initials, surname of other authors. Year of publication, title of article, title of Journal, volume (and issue number) as appropriate and page numbers.

Plant nomenclature:
Plant nomenclature is in a state of flux. Authors are thus advised to consult "The Plant List" (www.the plant list.org/1/) to ensure that the binomial used in their manuscript is the currently accepted name of the plant in question and the proper authority is named.

Copyright:
Before publication, authors are requested to assign Copyright to Tropical Agriculture. This allows Tropical Agriculture to sanction reprints and photocopies and to authorize the reprint of complete Issues or Volumes according to demand. Authors' traditional rights will not be jeopardized by assigning Copyright in this manner as they will retain the right to re-use and a veto over third party publication. The appropriate Copyright Transfer Form will be sent to authors when their paper has been approved for publication.

Offprints:
Authors are entitled to 30 free offprints of their papers when published. The offprints together with a complimentary copy of the Journal issue are forwarded on receipt of the postal charge of US$100.00