PROCEEDINGS OF THE

INTERNATIONAL SYMPOSIUM ON TROPICAL ROOT CROPS

held at

UNIVERSITY OF THE WEST INDIES

St. Augustine, Trinidad.

2-8 April, 1967

Volume I.

Edited by

Egbert A. Tai

W. B. Charles   P. H. Haynes

E. F. Iton   K. A. Leslie

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A GROUP OF PARTICIPANTS IN THE SYMPOSIUM

INTRODUCTION

FOREWORD

The International Symposium on Tropical Root Crops developed from an idea which originated in the Department of Agriculture, Crop Production, of the University of the West Indies in February, 1965. Because of the importance of the starchy roots and tubers as food in tropical countries and the emphasis placed by the University on relevant research, it was considered highly desirable that an attempt be made to collate existing information on these crops in order to identify gaps in our knowledge, make plans to fill these and also establish bases for practices aimed at economically expanding production and utilization.

Participation of scientists from different parts of the world was sought and made possible by the financial assistance given by internationally known organisations — The Rockefeller Foundation and the British Council — as well as others with local interests — Ministry of Agriculture, Lands and Fisheries of Trinidad and Tobago, Friends of the University, the Industrial Development Corporation, Trinidad Chamber of Commerce, Shell Trinidad Ltd., Texaco Trinidad Inc., Antilles Chemical Co., Chase Manhattan Bank, First National City Bank, Bank of Nova Scotia, Boots Pure Drug Co., Ltd., International Foods Ltd., H. E. Robinson & Co., Ltd., Empire Sales and Agencies Ltd. The contributions received covered all aspects of root crops production and use and were grouped under six headings as follows:

I. Breeding and Improvement
II. Physiology and Nutrition
III. Agronomy
IV. Crop Protection
V. Economics
VI. Storage, Processing and Utilization.

The Symposium was held at St. Augustine, Trinidad, on 2-8 April, 1967. A total of 157 individuals from 30 countries took part and 56 papers were read.

The participants were welcomed to Trinidad by the Hon. L. M. Robinson, Minister of Agriculture, Lands and Fisheries, and to the university campus by the Pro Vice-Chancellor, Dr. H. D. Huggins. The Hon. L. M. Robinson also opened the technical sessions. In addition to the six sections of the Symposium there were meetings of seven Study Groups and on the last day a Plenary Session.

These Proceedings endeavour to present an account of the papers delivered and the ensuing discussions. In the course of editing it was found desirable to rearrange the order of papers somewhat but in no instance was there any alteration of the content. The bulk of the work of editing fell on my co-editors as follows:

Sections I, VI	—	W. B. Charles
Sections II, III	—	P. H. Haynes
Section IV	—	E. F. Iton
Section V	—	K. A. Leslie

I must, however, accept responsibility for arrangement of the Introduction.

Presentation of the Proceedings in two Volumes was dictated by the amount of material to be published; Volume I. Contains the Introduction and Section I to III. Volume II contains Section IV to VI.

EGBERT A. TAI,
April, 1969.

ADDRESS OF WELCOME BY HON. L. M. ROBINSON, MINISTER OF AGRICULTURE, LANDS AND FISHERIES, TRINIDAD & TOBAGO

In the name of the Government of Trinidad and Tobago, I am very pleased to extend to you all a most cordial welcome. It is particularly gratifying to me personally that this second Agricultural Economics Conference and Root Crops Symposium is being held here at St. Augustine, and that the organisers seem to have taken the decision to make these conferences an annual affair.

The West Indian nations and territories have all, I believe, through this University and by other means, set about the not inconsiderable task of developing and building what I would term a national scientific personnel. It is only right, therefore, that opportunities should be afforded to our scientists, technicians and administrators to meet to exchange ideas, discuss their problems, and plan the future direction and orientation of their efforts in this very crucial field of agricultural development. It would be tragic indeed if no means of association existed and if everyone endeavoured to plan and work in isolation, divorced from each other in the Caribbean region and possibly also from the international scientific community of which we are a part.

I am perhaps laying too much stress on this point, since I notice from your programme that papers will not only be presented by West Indians, but also by some very distinguished people from other parts of the world. I feel, however, that this is something that should be repeatedly and continuously emphasised until it is understood and comprehended by everyone involved.

An associate of mine once said, that we in the West Indies are famous for imitating, emulating, but never originating, except for the steelband; and it is time that we attempted to change this state of affairs—especially since we have the talent and get down to the task of finding solutions to our problems — problems which in many respects may be unique to our region.

I do not subscribe to this comment in its entirety, but I believe that there is much we can do to speed up the diversification and the development of our agriculture along new lines and in new areas of specialisation.

I do not think that I am being melodramatic when I say that this is a critical period for West Indian agriculture. Our staple export commodities are being sold on a buyer's market, and we are entering a period when preferential arrangements in our traditional market, the United Kingdom, are likely to be progressively removed. People like yourselves working in agriculture have a special responsibility, therefore, to widen our horizons and give direction to our efforts so that West Indian agriculture can meet the challenge with which it is confronted in the second half of the twentieth century.

During your stay here an opportunity will be provided for you to become better acquainted with what we are attempting in agriculture, and I trust that you will not hesitate to call on my officers and myself as we are ready to be of assistance.

Once again I welcome you most heartily to our island, and hope that your stay will be extremely pleasant and rewarding.

ADDRESS OF WELCOME BY DR. H. D. HUGGINS, PRO VICE-CHANCELLOR UNIVERSITY OF THE WEST INDIES

St. Augustine came into being as an institution for teaching and research in agriculture 45 years ago and one may liken the event to a marriage. If you liken it to a marriage I would remind you that the appropriate stone or symbol on the 45th anniversary in marriage is the sapphire. Since the sapphire is a fancy form of bauxite it would permit me to make the point that the research work with bauxite in British Guiana was merely one of the activities whose remarkable achievement in the early years of this century brought to the attention of the world the potential of an institution such as this for the procreation of research work and research workers. If according to the precepts of Ecclesiastes we would praise these famous men there is none whose praise would be louder than Sydney Cross Harland, whom it is a pleasure and an honour to have with us today.

The United Kingdom Government and others have contributed generously to this institution. Few investments have rewarded better either in the United Kingdom, the West Indies, or elsewhere. With tropical agriculture mostly a supplier of raw products and with terms of trade tending to move against raw products, the primary producers could in the 1920's and 1930's place their main hope in higher productivity. None can estimate what was owed in those years to these agriculturists trained at St. Augustine and who headed soil surveys, pest control units, field experiment stations, research units, agricultural departments throughout the tropical and sub-tropical world.

This is the record, the tradition of which the School of Agriculture is today the lineal descendant. No finer tribute could be paid to this tradition than that this symposium, organised by the School should have attracted so international a gathering. With many of you, as with us, an intractable problem in economic development is rapidly increasing agricultural production and agricultural productivity. One advantage of this institution is the wide range of conditions and experiences which it encompasses. Thus let us take the subject of this symposium — the production of more food and of root crops, particularly. Jamaica with 1964 figures of production of goods and services amounting to $1,200 million with 13% contribution from agriculture (compared with Trinidad's production of goods and services amounting to $1,000 million with 10% contributed from agriculture) has imports of food per annum of $57 per capita of population (compared with $90 per capita food imports into Trinidad). This means that the imports of food per capita are some 60% higher in Trinidad than Jamaica.

I have learnt from Professor Tai's informative article, which appeared in today's newspaper, that the definition of a symposium is a "drinking party — a convivial meeting for drinking and intellectual entertainment." I gather that this symposium is carefully respecting that order of precedence. I wish the symposium well in both spheres.

STATEMENT FROM THE FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

presented by

D. C. Giacometti

I want to express warmest thanks for the kind invitation which has been extended by the St. Augustine University of the West Indies, Trinidad to Dr. B. R. Sen, Director-General of the Food and Agriculture Organization of the United Nations, in whose name I would like to convey to this International Symposium on Tropical Root Crops sincerest wishes for a successful development.

I am, furthermore, particularly pleased as a staff member of the Plant Production and Protection Division to express our Director, Dr. Vallega's gratitude and enthusiasm for the institution of this International Symposium. To us all this seemed a long overdue necessity for placing more attention on a group of crops which will have to play a far more important role than we can possibly imagine in solving the enormous problem with the few means at our disposal of how to feed the fast growing population of the world.

This is the present situation: something like one half of the world's peoples are underfed or illfed, or both. More than three million people die every year from protein malnutrition and many millions are believed to be psychologically retarded due to this fact. On the basis of the present projections of population increase of 2.5% to 3% per annum in Asia, Africa and Latin America, in 1985 there will be one milliard and a third more people than in 1965 sitting down to eat in developing regions. Even if the birth rate were to be lowered substantially, the effect of family planning would only show after more than a decade due to the enormous fertility potential in years to come caused by the present age structure in these countries where between 40 and 45% of the population is under 15 years of age.

The only solution to this problem in the next two decades is, therefore, to increase sustantially the world's agricultural production.

Agricultural production is increasing now probably faster during any previous period. For the last few years, however, it has not kept pace with the growth of the world's population. What is particularly disturbing is that in developing countries the average increase in production has only been 1.1% against a population increase of around 2.5% per annum, and it is not difficult to imagine the consequences that this will have, both from a social and political point of view, unless a change can be brought about in the immediate future.

Dr. Sen recently stated that a minimum increase per annum in food production of 3% is considered necessary so as to be sure of keeping just ahead of population increase, and an increase of nearly 4% per annum has to be attained if we are to provide substantial progress towards an adequate level of nutrition and avoid a further drain of foreign exchange from developing countries by forcing them to import food stuffs from developed countries.

This task is overwhelming and can only be faced and solved by strengthening and concentrating all our efforts in each single agricultural commodity.

Despite the fact that both the area under root and tubers and the production of these crops is relatively small compared with the world production of other staple food crops such as cereals, in 1964/65 the area under cassava, sweet potatoes, yams and potatoes amount to around 50 million ha. against 624 million ha. under cereals. The dry matter production (on a basis of 4:1 root to cereals) reached only 125 million tons in roots as against 1022 million tons in cereals. This wide ratio of 1:9 of root to cereals narrows where root and tuber crops are the main source of energy in the daily diet namely in those countries where agroecological conditions are unfavourable for an economic cereal production.

Most of these countries lie in the tropics, 20° North and South of the Equator. Except for the Asia region of this belt where rice is the staple crop and successfully competes with the root crops, the ration therefore remaining practically unchanged at 1:8, the ratio narrows substantially in the Central and South American region to 1:3, and in Africa even to 1:2.

(The figures are based on FAO statistics 1964/65 giving the amounts of production in the Belt for Asia (India excluded) for cereals to 45½ million tons, roots to 5.4 million tons, for Central and South America (Mexico excluded) for cereals 25 million tons, root 7.4 million tons and for Africa cereals 24 million tons, root 12.6 million tons)

But still more impressive is the superiority of the roots in carbohydrate production per ha. over that of cereals. In Central and South America 1.3 tons/ha from cereals against 2.8 tons/ha from roots, in Africa 0.9 tons/ha from cereals, 1.5 tons/ha from roots; and in Asia 1.5 tons/ha from cereals and 1.9 tons from roots.

These figures clearly show that in fact root crops as the highest yielding sources of carbohydrates can play a role in the world's fight against hunger through direct consumption by man and still more through indirect consumption as the energy basis of the feeding stuff for pigs, poultry and other animals.

We are, therefore, most impressed by the magnitude of leading papers to be discussed during this Symposium and are really enthusiastic that the long neglected crops with their great yield potential and by far not fully exploited possibilities for improving their nutritive value, are covered in all important aspects.

FAO is directly interested in assisting member countries in the implementation of projects aimed at the development of root crops production in various ways. The resources of FAO in this connection may be rather limited in comparison with what is required but by making use of various programmes such as the United Nations Development Programme (UNDP), the Expanded Programme of Technical Assistance (EPTA), the Freedom from Hunger Campaign (FFHC), the World Food Programme (WFP), and the Joint FAO/IBRD Co-operative Programme, it will be possible to offer useful assistance on countries' requests.

Study Group I

THE EVALUATION AND UTILISATION OF GENETIC RESOURCES IN TROPICAL ROOT CROPS.

Jorge Leon (Chairman)	F. W. Martin
Lucien Degras	O. G. Moscoso
A. S. MacDonald	D. B. Williams (Secretary)
M. L. Magoon	D. E. Yen

The genetic resources available in the field of tropical root crops include not only germplasm of the species involved, but also the body of information concerning each species, and the trained personnel capable of best utilizing such materials and information. The adequate utilization of these resources could best be stimulated by developing better systems of communication. When plant breeders and geneticists are better informed, they are more able to make rational decisions concerning programmes and objectives.

To facilitate communication, the Study Group recommends the establishment of a Tropical Root Crops Newsletter. The proposed newsletter would contain address lists of persons working on the genetics or breeding of such crops, periodic bibliographies of recent papers, lists of stocks or materials available for exchange, periodic summaries of the status of particular crops and short, informative research noted.

It is also suggested that the newsletter serve as the publication of a Root Crop Development Cooperative. The organisation would serve not only to publish the annual letter, but would also serve to coordinate efforts to establish and maintain germ plasm collections. In addition, the possibility is visualized of the growth of this organization into a Root Crop Society.

In order to organize such a Cooperative, an organizing committee should be constituted. The current study group has asked Dr. Jorge Leon, Inter-American Institute of Agricultural Sciences, Andean Zone, Apartado 478, Lima, Peru, to act as temporary chairman. Volunteers to serve on such a committee include :

L. M. DEGRAS, Director, Station d'Amelioration des Plantes,
Institut National de la Recherche Agronomique,
Centre Antilles-Guyanes, Petit Bourg, GUADELOUPE.

ANDREW S. MacDONALD, Makerere University College,
P. O. Box 262, Kampala, UGANDA.

M. L. MAGOON, Director, Central Tuber Crops Research Institute,
Indian Council of Agricultural Research,
Trivandrum, Kerala, INDIA.

FRANKLIN W. MARTIN, Federal Experiment Station,
Mayaguez, PUERTO RICO 00708.

D. B. WILLIAMS, Plant Breeder, Food Crops Breeding Unit,
Faculty of Agriculture, University of the West Indies,
St. Augustine, Trinidad W. I.

D. E. YEN, B. P. Bishop Museum, Honolulu, HAWAII.

In addition, other volunteers for this committee are needed, and interested persons are advised to contact Dr. Jorge Leon.

It is proposed that the committee organize and present a newsletter within one year of its beginning. Until the committee can develop a standard policy, contributions intended for the newsletter should be sent to Dr. Leon. Contributions most appreciated at the present time include names, addresses, and programmes of persons working with root crops and lists of plant materials available for exchange.

Naturally, the organising committee will be concerned with developing a sound financial backing for the proposed Cooperative and Newsletter. Until an adequate study of financing can be managed, the study group proposes that any persons interested in participating in the Root Crop Development Cooperative and/or receiving the annual Tropical Root Crop Newsletter, contribute one dollar U.S. to the temporary chairman.

The study group also recognizes that certain current collections of root crops are in danger of extinction. We recommend that sincere efforts be made to preserve these until the Root Crop Development Cooperative is in a position to aid in their maintenance.

The volunteer committee earnestly seeks suggestions and advice from interested persons, especially during the crucial early phases of this proposed project.

Study Group 2

THE USE OF PHYSIOLOGICAL PARAMETERS IN ROOT CROP BREEDING

H. A. Steppler (Chairman)
T. Hernandez
E. C. Humphries
F. W. Milthorpe
W. V. Royes
G. Sidrak
A. D. Skelding
J. A. Spence
L. A. Wilson (Secretary)

General Remarks

The committee was able to consider the use of physiological parameters in improving the production of tropical root crops, only in the most general sense. We believed that there was too little knowledge available on which to base concrete recommendations for a sophisticated breeding programme. Generally, the selection, improvement and general agronomic techniques concerning tropical root crops such as sweet potato, cassava, yam, and the aroids are relatively poorly developed and understood in comparison with cereals, fibre crops and even the temperate root crops such as the edible Solanum potato. Also, the degree of understanding and progress towards adequate levels of production vary in different areas of the tropical world. Accordingly, we make the following suggestions on an approach to the problem, recognising that some of our suggestions have already been implemented and the desired result achieved with some crops, in some regions e.g. sweet potatoes in the Southern United States and Solanum potatoes in Venezuela. It is our feeling that the experience gained in such regions should be utilized as far as possible in other regions — climatic, economic and other factors permitting.

Basic Work

An important pre-requisite of any breeding programme is the collection and classification of the main varieties of the area in order to select the most promising ones from existing material. Collection of cultivars from regions of similar climate, but with longer experience and more advanced breeding programmes, should also be made and the cultivars evaluated under local conditions.

Concurrently with the initial collection, classification and selection of cultivars steps have to be taken to improve the general agronomy of the species, recognising the major disease and insect pest problems.

The major requirement for improving agronomic practice is the definition of the factors limiting the yield of the chief varieties in the local environment and hence identification of the areas where significant responses to treatment may be obtained.

Studies along these lines should indicate whether :

1. the problem of improving production is essentially one of management such as manipulation of the environment to suit the species, by altering date of planting, rate of planting, fertiliser application and other agronomic practices

2 the problem is one of breeding a new cultivar to suit the environment, as illustrated by resistance to disease or changes in growth pattern etc.

3 a combination of both factors.

It is suggested that growth-analysis techniques be used at this stage, with particular reference to the development of the leaf surface and of the storage organ, throughout the normal growing season. When this basic information is satisfactorily documented one can then proceed to the next major step in the programme.

We shall assume that the basic work indicated that this step calls for plant breeding.

Breeding Programme

As a basic premise, we agree that the ultimate objective of a breeding programme is to maximize the ability of the plant species to contribute food for man. This objective, in a very broad sense, can be achieved in two ways, namely :

1. by improving the performance of the plant species within the environment in which it is destined to be grown.

2 by improving the nutritional value of the edible portions of the plant.

The degree of sophistication of the agriculture and of the consumer in the region concerned will dictate the relative importance of the two factors. Thus, shape, size and colour of tuber, consistent with a "grade standard," may have greater relevance in some areas than nutritional value in itself.

The most difficult problem facing us is to define in unambiguous terms, the objective of the plant breeding programme. A clear and concise definition of objective, implies a ready determination of the essential parameters of the breeding programme. In our opinion, the plant physiologist has a vital role to play in such a definition.

Role of the Plant Physiologist

We envisage at least a four-stage involvement of the physiologist in the definition of the breeding programme, as follows.

1 To identify the physiological parameters which are basic to the yield potential of the species.

2 To determine those factors which are inhibiting the species in the expression of its maximum potential.

3 To assist the plant breeder in establishing the range and sources of variation which exists for those particular parameters, in order that he may determine their heritability.

4 To provide the plant breeder with simple techniques of measuring relevant parameters in individual plants in segregating populations, and hence of selecting effectively for improvement.

An increase in the yield of the economic portion of a species will most likely be achieved by selection for an increase in edible plant material in relation to the total dry matter, whilst increasing the total dry matter. The area of responsibility of the physiologist is to provide the basis for this selection.

Physiological determinants of Yield

We do not feel that we should attempt here to enumerate physiological parameters that might be used in a breeding programme. It is suggested that these should be worked out for individual crops and if necessary for particular environmental conditions. We draw attention, however, to two ways in which this problem can be investigated. These are :

1 The analysis of the contribution to yield to a high-yielding variety compared with a low-yielding variety.

2 Consideration of the factors which have been previously found to be important determinants of yield in other more thoroughly investigated crops.

The physiological explanation of yield can be investigated by the physiologist using growth analysis techniques. So far there have been few investigations of this type and these have been done mainly on temperate crops. Before definite recommendations can be made to the plant breeder, there is need for more growth analysis investigations on tropical root crops.

In temperate crops, the important contributory factors to high yield are :

1. early establishment of a large leaf area.

2 maintenance of leaf area near the optimum level for as long as possible.

3 maximum diversion of dry matter into the economic portion of the crop.

Leaf efficiency as assessed by net assimilation rate does not seem to be a very important attribute although differences in the net assimilation rate are found between varieties and especially with age within the one variety.

Although similar factors are no doubt involved in yield determination of tropical root crops it is felt that the differences between the temperate climate and the tropical climate and indeed between the wet tropics and the dry tropics are so great, that separate investigation is required with particular reference to the tropical environment.

It is also certain that there will be physiological parameters other than already mentioned which are very important in particular areas. Examples could be dormancy, obtaining tubers of the correct physiological state at planting, obtaining varieties which will tuberize with high levels of nitrogen nutrition, and so forth.

The Tropical Environment

It is suggested that breeding programmes and agronomic trials should be supported by climatological records of pertinent aspects of the environment especially soil moisture deficit (from rainfall and evaporation estimates) and potential transpiration and temperature.

It is also felt that great advantages in production may be derived, in some tropical climates, from growing more than one crop in any year. The accurate documentation of annual climatic variations with an aim to fulfilling this possibility is therefore recommended.

Quality

Quality has not been a major consideration in our discussions because we feel that quality is largely determined by local preference. Quality considerations are important, however, and must be related to the utilization of the product.

Tropical root crop quality, for human and animal consumption, for processing and for manufacturing new products such as starch should be taken into consideration in breeding programmes, whenever this is possible. This may be achieved without being the primary objective of the programme by making routine records of the following characteristics of all promising varieties :

1. size, shape of roots and colour of skin and flesh
2. chemical composition of roots
3. keeping quality of roots
4. cooking quality of roots

In conclusion, we recommend that careful consideration be given to the conditions for which new varieties are to be produced. The variety for a subsistence agriculture may not at all be suited to a sophisticated cultivation system. A wet season variety may also require altogether different characteristics from a dry season variety.

We recommend that in areas concerned with these crops there should be teams consisting of agronomists (or horticulturists), plant physiologists, and plant breeders to explore the more important crop in the region in the detail necessary for adequate understanding of the relevant issues. Inter-Regional collaboration should be actively encouraged.

Study Group 3

ECONOMIC AND AGRONOMIC FACTORS LIMITING LARGE SCALE ROOT CROP PRODUCTION

G. Samuels (Chairman)
E. G. B. Gooding
J. Johnson
K. A. Leslie
H. McConnie
J. G. Ohler
J. Nabney
E. C. Pilgrim
R. W. Radley
B. T. Stephenson (Secretary)

General

Large scale root production is defined as a large acreage unit of farm land devoted to a given crop rather than a large total production of a root crop due to the sum of production of many small farm units. Large scale root production in this report will be based on mechanization of as many field operations as possible rather than the use of hand labour, inasmuch as future indications in many parts of the world reveal a shortage of cheap available labour for such agricultural crops.

Procedure

A questionnaire covering the main possible limiting factors, both agronomic and economic, which can limit large scale root crop production was circulated among the 23 countries represented by our symposium delegates. The results of these questionnaires were tabulated on the IBM Computer to give a fairly comprehensive picture of factors which might limit root crop production.

Preliminary Results

A preliminary scanning of the data indicates that limiting factors to large scale root crop production are more economic rather than agronomic. Sufficient land appears to be available for mechanization in most countries. However, further information and experience is needed in the proper machines for planting and harvesting mechanically.

The economic limitations are apparently based on prices of the product, lack of markets (local and export), seasonality of production, and lack of information of cost of production of the various agronomic phases of mechanizing the root crops. The lack of proper marketing facilities and apparently large mark-up in price between farm price and retail price was indicated in a majority of the countries.

A large group of countries indicated the possibility of processing of root crops (especially cassava) as a means of making the mechanization of root crop production economical. However, more information is needed as to actual feasibility in the particular crop and country.

Study Group 4

IDENTIFICATION OF AREAS NEEDING FURTHER ELUCIDATION IN DISEASE OCCURENCE ON TROPICAL ROOT CROPS

W. J. Martin (Chairman)
R. Barrow
R. Gallchet
F. Itou
E. Jones
J. Mills
S. Parasram
R. Pierre (Secretary)
E. R. Trujillo

The opinion has often been expressed that tropical root crops are largely free of diseases and pests. We consider this idea to be an erroneous one and attribute this error largely to an insufficient awareness of the problems which exist. Indeed, the lists of diseases and pests reported on tropical root crops are short in comparison to those on most other cultivated crops. A brief and incomplete examination of the literature indicates that some 16 fungi have been associated with root rots and necrosis of the above-ground parts of **Manihot esculenta.** Several fungi have been associated with diseases of **Colocasia esculenta, Xanthosoma sagittaefolium, Dioscorea** species and **Maranta arundinacea.** In addition, bacterial, virus and nematode diseases are known to occur on most of these crops. Many of the virus diseases are transmitted by aphids and white flies, and several other insect pests are known to cause damage to the aerial and under-ground parts of these root crops.

In general, very little work has been done on tropical root crops and therefore information is limited on several aspects of root crop production. It is, perhaps, not altogether insignificant that **Ipomoea batatas**, the root crop which has been studied most extensively, also has the largest number of recorded problems. There are at least 30 fungal diseases, 7 virus diseases, 3 nematode diseases, and 7 major insect pests of this crop.

Let us now examine some of the factors in root crop production which particularly favour the development of diseases and pests.

1. Root crops are all vegetatively propagated. They thus provide excellent reservoirs for viruses and other pathogens.

2. The economic parts of these crops are underground and thus are liable to direct attack by soil fungi, bacteria, nematodes and insects.

3. The location and methods of harvesting the economic parts of these crops facilitate wounding thus providing ready avenues of ingress for pathogenic organisms which may cause considerable damage in storage.

4. The long duration of growth and the growing season (wet) of most tropical crops are likely both to enhance the incidence of disease and to render control measures difficult and expensive.

Undoubtedly, diseases and pests are limiting factors in the production of tropical root crops. However, we feel that the information available is insufficient to permit us to assess fully the magnitude of the problem. Perhaps one of the most important factors contributing to this dearth of information, particularly in the Caribbean area, is related to the system of producing these crops. Until very recently, root crops were produced almost exclusively by small farmers and backyard farmers in small plots. Under such a system, plants may genuinely escape disease and pest damage, or their susceptibility may go unnoticed principally because of the small acreages involved. Invariably the incidence of disease and pests increases as the acreage of a particular crop is increased. It should, therefore, be reasonable to expect that with the contemplated increased emphasis on the production of tropical root crops, little known and previously unknown diseases and pests will become evident, as in the case of **Colletotrichum** disease of **Dioscorea** which now is present in the West Indies

In view of the problems outlined above the study group concerned with the pathology and entomology of tropical root crops considers it extremely difficult to isolate specific areas needing further elucidation. Indeed, this study group considers that the entire field stands in need of elucidation and agrees that careful consideration should be given to the following points:

1 The personnel engaged in research on diseases and pests of tropical root crops are far too few to cope effectively with the present and potential problems.

2 The group recognises the need for greater emphasis on research, and strong support for the development of departments in the sciences of entomology and plant pathology in tropical countries

3 With the present limited number of personnel engaged in research on diseases and pests of tropical root crops every effort should be made to encourage co-operative ventures such as seminars, symposia and exchange of bibliographical compilications. In the opinion of the group the importance of such activities cannot be over-emphasised

4 Exclusion of pathogens and pests that are not present in given areas is an extremely valuable aid in combating diseases and pests. Adequate attention should therefore, be given to quarantine regulations and measures, both on a regional and territorial basis, to avoid the introduction of new diseases and pests.

5 Programmes for the improvement of tropical root crops by breeding and selection should include screening for resistance to diseases and pests as a major objective.

6 Increased attention should be given to the efficient use of modern chemical, biological and cultural control measures, e.g. disease-free planting material, crop rotation and field sanitation.

Study Group 5

THE FUTURE OF ROOT CROPS AS A SOURCE OF CARBOHYDRATES

B F Johnston (Chairman)
M. Alexander (Secretary)
C. P Cacho
D. T. Edwards
V. Ferrer
B Yankey

It is clearly important but also extremely difficult to assess the future position of the tropical root crops as a source of carbohydrate. Their importance in human diets will depend upon the interaction of three factors:

1 the costs of producing root crops compared with competing staple foods — notably the cereal crops;

2 the extent to which the farm level price is increased by costs of distribution and processing; and

3 the extent to which the farm level price is increased by costs of distribution and processing; and

3 consumer preferences which determine the quantities consumers are prepared to buy at various prices. The future demand for starchy roots as livestock feed will depend essentially on their comparative cost as the energy component of livestock rations.

There appear to be large differences in the extent to which the tropical roots are able to compete on a cost basis with other sources of carbohydrates. Under traditional systems of farming they are capable of giving yield per acre of product and of calories that is high relative to the alternative crops available. They are also capable of giving relatively high yields per man-day, although yams tend to be relatively demanding in their labour requirements whereas manioc is particularly cheap to produce.

They are, of course, large local variations in yields and production costs depending on the root crops, the variety grown, and the technology used. In addition, there appear to be rather striking regional differences in the relative costs of the root crops and competing staple foods. In tropical Africa, the root crops, and again manioc in particular — tend to be the cheapest sources of food calories in the humid and subhumid areas where they thrive. The situation is very different in the West Indies. Price data indicate that local root crops are about as costly on a weight basis as imported cereals which means that in terms of calories they are something like three times as expensive. The foregoing price comparison applies to the retail price of fresh roots and therefore is in part a reflection of the rather high costs of transporting, storing, and handling the root crops because of their bulky and semiperishable nature. There is also a tendency for fresh roots to be relatively more expensive in urban centres in Africa, presumably for the same reason. But in a number of African cities at least one processed root product — manioc meal or gari — is the cheapest source of food calories.

Judging by the experience of the last half century and more in the West Indies, there is a strong tendency for consumers to shift from root crops to rice and wheat products as they come to rely increasingly on purchased food. This shift has been possible because of fairly high foreign exchange earnings from sugar and other exports that have provided the foreign purchasing power for very heavy reliance on imported cereals. In fact, apart from farm households that still subsist mainly on their own production, the root crops have become primarily a vegetable food that adds variety to the diet rather than a staple food. It seems likely that at present the local root crops compete much more with imported Irish potatoes than with the imported cereals.

Although imports of wheat products, and in some countries rice, have increased sharply in tropical Africa, food imports have not as yet become highly important. In a few instances there appears to have been a tendency for growing demand in urban areas to be satisfied by imports rather than expanding the flow of indigenous roots and other staple foods, but that appears to be the exception rather than a dominant feature as in the West Indies. Although it is certain that total demand for food will grow rapidly with the growth of population and rising per capita income the effect of this on the root crops is uncertain. Total and per capita consumption of root crops in tropical Africa will no doubt continue to increase for some time until incomes rise sufficiently to permit a substantial shift to preferred foods — initially wheat production or rice and eventually high cost but preferred items such as meat and dairy products. In the West Indies growth of demand associated with population increase may for a time, offset the trend toward declining per capita consumption that will probably continue. The view was advanced that efforts to promote consumption of local root crops, for example popularizing new techniques of production or introducing processed products with the transport and handling characteristics of the West African gari or Brazilian farinha da mandioca might slow or even reverse the trend toward declining consumption. But this is highly speculative, and it is understandable that, from the demand point of view replacing imported "Irish" potatoes by local production is receiving much attention.

The statement is subject to many qualifications. Even more important than the time limitation under which the committee operated is the lack of reliable information concerning consumer preference in various areas, comparative costs of production and comparative cost of handling, storing and transporting of roots and cereals and of the different roots.

The committee was unable to get information on Latin America and Asia in making its recommendations and does not feel equipped and competent to formulate statements on the future of root crops as a source of carbohydrates for these areas. This study group would like to draw on the knowledge of people in these areas by

1 asking delegates from these areas their views and

2 by corresponding with experts based in these areas.

Study Group 8

ROOT CROPS AS PRIMARY SOURCES OF CARBOHYDRATE

E.H. Casseres (Chairman)
D.G. Coursey
B.N. Ghosh
M. Lines
A. El Mohandes
L.G. Sanguinetti
C. Seaforth (Secretary)
J. Thomason

This Report aims to identify areas where more work is required to increase the utilisation and processing of tropical root crops, and to show ways of promoting international cooperation in this field.

A. The major tropical root crops, arranged in diminishing order of knowledge as primary sources of carbohydrate are the sweet potato, the cassava, the yam and the edible aroids. The Study Group dealt with the following specific areas of the study of these crops.

1 **The need for more information on dry matter quality with respect to utilisation of tropical root crops as foods and feed stuffs.**

There is a need for large scale processing and a greater availability of tropical root crops as foods and feed stuffs.

(a) The Study Group noted the widespread importance of cassava as a food which grows under a wide variation of ecological conditions. For example, in India, in the State of Kerala where the Cassava averages over three million tons per year, semiprocessed cassava as chips have been used to help break a recent famine in the State of Behar. Satisfactory results are reported with the use of cassava and nutritive supplements to feed poultry and cattle in some parts of the world. This crop could be encouraged in tropical countries as a replacement for the expensive imported animal feed stuffs such as oats and maize. Through cottage industries in India the cassava is available in forms such as fried chips. The methods already in use have solved the problems of detoxification and of preserving the cooked cassava. Sun-dried chips can be stored for as long as six months. Cassava starch and glucose from the cassava are already in use in the United States, India and elsewhere. However, the cassava has perhaps an even greater future as a milled flour with properties useful for incorporation in bread manufacture and in other industries.

(b) The sweet potato is apparently the second world source of carbohydrates from tropical root crops. Although there are efforts to promote the use of yellow fleshed varieties high in carotene content the greater demand in some areas is for the white fleshed potato. And it is likely that this will continue until sociologists and economists encourage a change. Meanwhile, in Puerto Rico efforts are being made to improve white fleshed varieties for canning. Sweet potato cultivation for foods and feed stuffs should be encouraged in the tropical lowlands in place of less well adapted crops like the Solanum potato. It is hoped that the more extensive production of this crop could reduce the cost of production.

The sweet potato is already available in canned, chip and flake forms in the United States of America. Yams and edible aroids can be processed by the same equipment now used to process the sweet potato, provided the economic problems are solved. More attention should be paid to the quality of starch derived from these root crops to meet a specific culinary need. For instance, more studies should be done in relation to the texture required for the important West African yam food called "fu-fu," and "Poi" which is derived from the taro of the Pacific Islands.

(c) Compared to the cassava and the sweet potato, there is much less data available on yam and the edible aroids which are however grown largely as home garden vegetables in many countries. More of these root crops might be grown profitably in rotation with staples where they are now not grown in the tropics. They are highly accepted everywhere, and there may be surprisingly good returns from researches on the domestication of some of the less well-known yams (**Dioscorea** spp.) and edible aroids (**Xanthosoma** and **Colocasia** spp.).

(d) The existence of toxic **Dioscorea** species should be noted. They are used in an emergency as famine relief food, but with cultivation on a larger scale they should find more extensive useage as foodstuffs after processing which includes detoxification.

2 There is an urgent need for more information on proper handling and storage of all tropical root crops to extend their period of availability.

3 **Root crops as raw materials for industrial processes :**

There is a lack of information to determine whether the four main tropical root crops (sweet potato, yam, cassava and aroids) are interchangeable as raw materials for processing for industrial use

(a) Starch manufacture for the paper and textile industry from cassava and from sweet potato is already carried out in Mexico, East Africa and elsewhere. Glucose, alcohol and other products are also being obtained in India from the cassava. Inter-disciplinary teams of economists and horticulturists would consider in some cases the need for small factories and for plantations of tropical root crops to take the place of other starchy crops now grown only with difficulty.

(b) It is unlikely that yams and the edible aroids would in general be useful raw materials in industrial processes because they are grown mainly as food stuffs at greater cost than the cassava.

4 **The preparation of a monograph on traditional culinary methods used for tropical root crops in order to increase their utilisation :**

There is need to collect data on indigenous methods of use and preservation of tropical root crops. A working party drawn from participants at this symposium should collect recipes and socio-economic data relevant to the conditions under which the foods are prepared by traditional methods from tropical root crops, from country to country.

B. Another major recommendation of the Study Group is establishment of regional and international cooperation and regular consultation amongst workers in the field of tropical root crops utilisation. It recommends that support for this work should be actively sought from already established International institutions such as the Food and Agriculture Organisation of the United Nations, the Inter-American Institute of Agricultural Sciences of the O.A.S., and other interested organisations.

Study Group 7

THE SCOPE FOR IMPROVEMENT OF DIET THROUGH INCREASES IN THE NUTRITIVE VALUE OF TROPICAL ROOT CROPS

J. Moner (Chairman)
T. W. A. Carr
W. R. Charles
L. Cross
H. Jeffers (Secretary)
J. Rumard

It has been well established during this Symposium that dietary habits, scarcity of grains, and the availability and production potential of root crops in many regions of the tropics demand that tropical roots play a major role in supplying a large proportion of the daily food intake of millions of the world's population. The great advantage of these roots over other crops that can be produced in the tropics lies in their potential for supplying extremely large quantities of utilizable calories per unit of land area. This basic advantage, and the economics of commercial production require that primary emphasis in root crop improvement be given to increasing yields of edible roots.

Generally in areas where root crops supply the major portion of the daily food intake, protein and more specifically amino-acid deficiencies and under-nutrition are widespread. It is generally accepted that the protein quality and nutritive value of most tropical roots are very low; however, complete and accurate chemical and nutrient analyses for a wide range of genetic materials are not available to allow us to assess the improvement in nutritive value that might be possible from an intensive breeding and selection programme.

On the basis of these findings we would suggest that:

1. Any attempt to improve the nutritional level in certain tropical areas must involve some consideration of increasing and maintaining an adequate supply of total calories. This would indicate that major emphasis should be placed on measures designed to increase yield per unit area and to increasing total production. Selection of varieties for yield characteristics and improved agronomic practices would allow rapid progress to be made in increasing calorie availability.

2. Concomitant with selection for high yield: protein, amino acid, vitamin, mineral and toxic principle composition should be obtained for all available genetic materials. This will establish the feasibility and scope for improving the nutritive value of these tropical roots. It is recommended that arrangements be made for establishing standard procedures collecting, drying, handling and labelling of samples and that some institution be selected which has the capacity and is willing to undertake the analysis, compilation and distribution of these data.

3. Because of the low nutritive value indicated, the economics and feasibility of associated cropping of root crops with legumes should be investigated with a view to supplying a more balanced diet.

4. Studies be undertaken to investigate possibilities of incorporating dehydrated forms of these roots into acceptable, enriched food preparations and to assess the value of leaves of these crops as human food.

5 Possibilities be explored for increasing the utilization of roots and the leaves of these plants in stock feeds in order to increase the supply of dietary animal protein, and to reduce competition between livestock and humans for other food sources.

REPORT ON THE PLENARY SESSION OF THE INTERNATIONAL SYMPOSIUM ON TROPICAL ROOT CROPS SATURDAY, 8TH APRIL

After a short presentation to the Clerical Staff who assisted at the Symposium, the Meeting was opened and study group reports received. The Chairman thanked participants for the efforts taken in compiling these reports, and their adoption was carried unanimously.

The following motions were then tabled

A. 1. Whereas there has been a highly favourable international participation in the Symposium on Tropical Root Crops (ISTRC) sponsored by the University of the West Indies at St. Augustine, Trinidad.

2. Whereas there has been an expression by the various delegates attending the Symposium of the need for furthering the interest in research in tropical root crops, and

3. Whereas the papers presented by the delegates have been of valuable interest and contributed much to knowledge on tropical root crops, but there still remain many unanswered questions both in fundamental and applied research on this subject, it is hereby resolved that:

1. The members of the Organising Committee, the Chairman and Secretaries of the seven (7) Study Groups and any participants in the present ISTRC who are willing to volunteer shall form a Continuing Committee to disseminate the information gathered at this Symposium to the various individuals attending as well as institutions, agencies and firms, who may put this knowledge to use for the furthering of production of tropical root crop.

2. That said Standing Committee shall be empowered to solicit and choose the site of a second ISTRC to be held three years from now:

3. That the host institution for the next symposium shall take on the responsibilities, both financial and administrative, of the second ISTRC counsel from the original Standing Committee.

Moved by: Dr. George Samuels

Seconded by: Mr. P. H. Haynes

This was carried unanimously

B. 1. Professor H. A. Steppler moved and Dr. D. J. Rogers seconded the proposal that the Chairman and Secretary of the Organising Committee should hold the same offices in the Continuing Committee.

2. It was agreed that the hosts for the second Symposium should volunteer by September 1967 in order that adequate provision can be made for this Meeting.

3. It was agreed that a newsletter be published which would incorporate list of names and addresses of persons working on the genetics and breeding of tropical root crops periodic bibliographies of recent papers, lists of stocks of material available for exchange, periodic summaries of the status of particular crops and short informative research notes. The wish was expressed that the scope of this would increase in time.

4. Support of the Symposium for Dr. Montaldo's bibliography was expressed and the need to extend and to complete this work was indicated.

5 Mr. Coursey (subject to the approval of his Directors) was invited to chair a sub-committee to deal with the establishment of an Information Centre for Tropical Root Crops.

6 Professor Mahadevan invited participants to use the U.W.I. Library at St. Augustine as a repository for information on tropical root crops.

7 The Continuing Committee was charged with the responsibility of finding a chairman for a committee which would be assigned the responsibility of investigating the possibility of establishing an International Research Institute for Tropical Root Crops.

DEMONSTATIONS AND TOURS

I Laboratory — Coordinator, R. Pierre.

1 **Cytology of self-incompatibility in *Ipomoea* spp.**
(D. B. Williams and F. W. Cope).

2. Crop Protection.

(i) Macroscopic symptoms, and

(ii) Photomicrographs of disease causing organisms and cultures, of some root crop diseases,
(E. Iton and R. Pierre)

(iii) Life cycles and damage of some food crops.
(S. Parasram).

3 Physiology (J. A. Spence and L. A. Wilson),

(i) Demonstrations of mosaic sweet potato leaves.

(ii) A simple system of sand culture for nutrient studies

(iii) Reciprocal grafts of sweet potato cultivars

4 Feeding trials with rats on rations containing mixtures of dehydrated root crops. (H. Jeffers).

5 Anthocyan Evaluation — Demonstration of Chemical Assay of anthocyanin pigments in sweet potato tubers. (C. E. Seaforth).

II. Library

This display featured selections from the available material on tropical root crops and included books, pamphlets, journals and reprints. A bibliography of selected material accompanied the display. (Mrs. A. Jordan and Miss S. Evelyn).

III. Computer

1. Film (D. J. Rogers).

2. Some uses of the 1620 computer in agricultural investigations.
(D. B. Ainscough).

IV. Field Visit to Texaco Food Crops Demonstration Farm and the University Field Station

Coordinator, B. T. Stephanson

Texaco Food Crops Demonstration Farm

1. Development of mechanised root crop production.
(B. T. Stephanson, P. H. Haynes and Tractors & Machinery (Trinidad) Ltd.)

2 Root Crops grown on the farm. (P. H. Haynes).

3 'Irish' Potato Variety Trial. (P. H. Haynes).

University Field Station

1 'Irish' Potato Agronomy. (R. W. Radley).

2 (i) Range of Yam cultivars.

3 Crop protection chemicals and their application.

Tour A. Some Land Use Patterns in Trinidad.

Led by C. Brown and P. H. Haynes.

This tour was designed to introduce participants to the range of agricultural environment in Trinidad and to indicate the broad patterns of its exploration.

(a) Intensive Vegetable Production by small holders.
Aranguez Estates — A. MacMillan

(b) Intensive Vegetable Production on large scale
Trincity — P. Richards

(c) Land Settlement
Waller Field — E. J. Hamilton

(d) Forestry
Valencia, Long Stretch — H. Murray

(e) Citrus and Cocoa
El Reposo — E. J. Hamilton

(f) Coconuts and Beef Cattle
Nariva-Cocal — G. Boveli

Return via Brigand Hill — panoramic view of Nariva Swamp.

Tour B. Tobago.

This tour was non-technical and was devoted to sight-seeing and sea-bathing in Tobago.

INTERNATIONAL SYMPOSIUM ON TROPICAL ROOT CROPS

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ADDRESS

— *by* —

Hon. Lionel M. Robinson,

Minister of Agriculture, Lands and Fisheries Trinidad and Tobago

Ladies and Gentlemen :

I believe that it is generally accepted now that the development of agriculture is crucial to the economic success of the developing countries, and that as Professor Myrdal the renowned Swedish economist has said "it is a dangerous illusion to believe that there can be any significant economic development in these countries without radically raising the productivity of agricultural labour". The inference being that failure in agriculture will only result in total and complete failure with all that that signifies for the governments and peoples of all our countries.

The plight of the developing countries has been described and explained in depth — as we say these days, and I have no intention to outline the major factors responsible for this crisis as this has been so ably and so thoroughly done already. What I want to stress here, is that I believe that in large measure the solution for a significant proportion of our problems in the West Indies and in the developing countries around the world rests with people trained in your disciplines and possessing your skills.

We have been told and I accept the statement, that there is enough scientific and technical knowledge available for revolutionizing backward agricultural practices and modernizing the agricultural sectors of the developing countries. We have also been told and this may come as a bit of a surprise that despite the balance of payments and liquidity crises of the developed countries that the capital is available to meet the requirements for the modernization of the developing world's agriculture. I am not for a moment suggesting that all the capital should come from our friends in the advanced industrialized economies, but only that they have enough to fill the gap which will exist after domestic resources and savings have been tapped in the developing countries.

The figure given for the necessary annual investment for agriculture in Africa, Latin America, and Asia excluding mainland China is approximately $8.6 billion U.S. per annum of which $2 billion U.S. is said to be the foreign exchange component. The problem which exists, however, is associated with a rather new expression or piece of developmental jargon and this is "absorptive capacity". In the worlds of a World Bank expert "the gap which exists is largely a latent one; this latent need can become an effective demand for capital only as farmers increase their capacity to use and benefit from investments;" — and this my friends brings me back to you people.

Ministries of Agriculture in the developing world have the important and vital task of mobilizing and allocating their countries resources so as to realise or to use the economists jargon maximise the returns from agriculture. The direction for the country's effort in agriculture must come from them, but such a complex task especially in the developing world requires — and this is part of the job of mobilization — the concern and the attention of the country's best minds especially in the scientific field.

Scientific research and technological advancement and progress in the industrialized countries which has come from continuous effort and concentration on their particular problem has in turn created serious problems for us in the developing world and has brought us face to face with the problem of the displacement of our traditional exports by synthetic substitutes and further difficulties which have arisen from the so called "chemicalization" of industry. This is the dilemma which we face, science and technology can make us and break us, all apparently at the same time.

It would be folly and indeed impossible to try to contain or constrict the frontiers of knowledge; this has been tried previously only to fail utterly. What we have to attempt to do is to apply science and technology to the solution of our particular problems just as the developed countries have successfully applied them to theirs. But even this may not be enough, for as Professor Myrdal has said — "it is not enough to adapt and adopt modern technology in the developing countries, but to have a substantial part of an increased research activity directed to the concrete production problems in these countries where conditions are so variegated and different".

What he is in fact saying is that merely to attempt to adopt or utilise the most modern technology or scientific methods without finding out whether they are the most suitable or appropriate in the given circumstances may solve one problem and create two. What is required and what I believe is necessary if you pardon my presumptiveness is that our scientists and technicians should first of all try to fully understand the environment in which they have to work and as my economists friends tell me the factor endowments of their respective countries, that is how much labour to combine with capital given the fact that labour is the abundant resource in every case

A look at your programme of discussions has convinced me, however, that the emphasis at both the Symposium and the Agricultural Conference is on what I would term severly practical issues and problems which confront the West Indian farmer. I am quite impressed also by the people you have listed to present these topics. The Symposium and Conference will I am sure result in the presentation of many concepts and ideas which will be of great assistance to us all especially as food crop farming on a commercial basis as opposed to a subsistence level is becoming widespread in the Caribbean Region. We ourselves here in Trinidad and Tobago have in our Crown Lands Programme fixed targets for the establishment by 1970 of over 900 foodcrop and vegetable farms, so that our interest in the proceedings here is more than assured.

I have already taken up too much of your valuable time, so I will leave you to your deliberation which I have good reason to believe will be both rewarding and path breaking. My country is indeed proud to be host to such a distinguised gathering.

Thank you.

THE STERILITY-INCOMPATIBILITY COMPLEX OF THE SWEET POTATO

— *by* —

Franklin W. Martin,
U.S. Department of Agriculture, Mayaguez, Puerto Rico

Sex has been well- established as the almost universal method of reproduction among animals and plants. The sexual process has many advantages to the species, chief of which is that it results in a constant reassortment of the genetic material, thus giving rise to new combinations which may have superior value. But the sexual process is complicated and demonds a high order of control of physiological processes, and exact timing of events. The genetic information must be systematically halved, and the two halves from different parents intimately re-united. The newly formed individual must then be nurtured to a state of independence from either parent. Because the process is complex, it may be disrupted in numerous ways. Capricious external forces, inner physiological disturbances, or inadequate information from the genes themselves may interrupt any of the long series of steps in the normal reproductive process, reducing the potential number of progeny. We call this result sterility, but sterility is but an end product. In animals and plants, the study of sterility producing systems may not only be fascinating, but has numerous practical ramifications in everyday life.

It is interesting and noteworthy that plants in contrast to animals, usually have the two sexes in one individual, very often within a single flower. Thus, mating of identical male and female may occur, which restricts exchange of the genetic material, and leads successively to a more homogenous and uniform progeny. In such cases the advantage of sex may be lost. It is not surprising, therefore, that various physiological processes have developed in flowering plants to impede the process of self-fertilization or increase the likelihood of crossing. Some of these mechanisms are self-evident. For example, bright-coloured, odorous flowers attract insects which inadvertently carry pollen and affect fertilization. In some cases, parts of one sex mature before the corresponding parts of the other, thus leaving an interval when crossing can occur but not selfing. A series of related processes in which self-fertilization or seed production is impeded by internal physiological systems are grouped under the name self-incompatibility.

It is important to distinguish here between self-incompatibility and sterility. In the case of self-incompatibility, all sexual processes are normal. Viable gametes are produced. But gametes from the same or genetically distinct plants, may function perfectly. Thus, the plant is not sterile *per se,* except in matings to itself. Therefore, self-incompatibility has sometimes been called self-sterility. The distinction between sterility and incompatibility is of particular importance when one begins to study poor fruit or seed set in specific plants. Fortunately for the geneticist, these processes usually occur separately, and thus can be studied independently.

But when sterility and incompatibility occur in the same species, separating and understanding the various systems may indeed be a puzzle. Now so far I have talked as if sterility were the exact opposite of fertility, and self-incompatibility the exact opposite of self-compatibility. Thus, I might have given the impression that these two kinds of behaviour are each expressed in only two ways. But in reality, all sorts of intermediate behaviours occur, which we might call partial sterility or partial self-incompatibility. I have the good fortune of presenting to you today some data and some opinions concerning a plant that demonstrates very well the complexities of both kinds of behaviour, the sweet potato.

The sweet potato ranks third in importance among vegetables in the United States. It is now widely distributed through both temperate and tropical areas. Although discovered by the first Europeans in the Caribbean, some studies suggest that the sweet potato was well distributed by man throughout the Pacific, at a still earlier date. Because the sweet potato is fleshy and herbaceous, its remains have not been well preserved among archaeological relics. Storability of the tubers and the ease of propagation from the stems have contributed to the sweet potato's popularity before and now.

What kind of a plant is the sweet potato? When the geneticist asks this question he is really asking, "What kind of a breeding system does it have, in contrast to other plants?" The sweet potato is a hexaploid with 90 chromosomes. In contrast, all but a few species of *Ipomoea* have 30 chromosomes. The chromosomal behavior of the sweet potato is normal, but some secondary pairing during meiosis suggests that similarity exists between the different pairs of chromosomes. It is probable that the sweet potato is the result of hybridization of two *Ipomoea* species followed by chromosomal doubling

The flower of the sweet potato is pinkish and attractive. It readily draws insects, especially honey bees. But propagation by cutting is the usual practice. There is some suggestion that even the more primitive sweet potato varieties are highly selected. Progeny of superior varieties include large numbers of off-types, including those with only small storage roots, and twining, climbing habit. Very little of the genetics of the species is known.

In order to overcome disease susceptibilities, considerable work has been expended to breed and improve the sweet potato, and such efforts continue. The usual method has been to cross-pollinate varieties having characteristics desired in a single variety, and to select among the progeny for the desired type. New varieties are released after much elimination during years of testing Thus, each variety represents something carefully screened and chosen as the almost ultimate expression of the desired characteristics. Two problems have impeded breeding efforts. One of these is the reluctance of varieties to flower under temperate zone conditions. This problem can be avoided to some extent by various flower-inducing procedures. The second problem has been the occurrence of relatively low levels of seed set after both self- and cross-pollination. And, of course, that problem is the one we are concerned with today.

Let us take a look at some fertility measurements of the sweet potato. Ultimately, fertility must be considered the ability to produce offspring, seed. If we take a large number of sweet potato crosses made under ideal conditions, and classify the crosses by number of seed per pollination, we obtain a hyperbolic distribution (Table I). From the table it is evident that the vast majority of the crosses set few seeds. It is also evident that very few crosses set even 50 per cent of the available ovules. If we examine another measure of fertility, fruit per pollination, we see a similar curve. Now what do these two curves mean ? What do they tell us about the breeding system of the plant ? They say that the normal situation is reduced seed set, or partial sterility. Why not incompatibility ? A brief discussion will show why this curve is produced primarily by sterility systems and only secondarily by incompatibility.

Table 1. Distribution of fruit and seed set in crosses of the sweet potato

Percentage Class	Number of examples per class Fruit Set	Seed Set
0.0	38	39
0.1 — 6.0	20	47
6.1 — 12.0	19	18
12.1 — 18.0	13	17
18.1 — 24.0	6	7
24.1 — 30.0	7	7
30.1 — 36.0	5	3
36.1 — 42.0	6	2
42.1 — 48.0	5	1
48.1 — 54.0	5	0
54.1 — 60.0	5	0
60.1 — 66.0	5	0
66.1 — 72.0	1	0
72.1 +	7	0

In the simplest possible case of self incompatibility when only two self-incompatible, inter-compatible types exist, half of the crosses would be fertile and half would be incompatible (Table 2). By adding another plant the number becomes 2/3 fertile and 1/3 incompatible. Similarly, each newly added incompatibility type increases the percentage of fertile and decreases the percentage of incompatible matings.

Table 2.—Percentage of compatible matings as compared to number of compatibility groups.

Incompatibility Number of groups	*Kind of Number of matings**	*Incompatibility Number of matings*	*Fertile Percentage matings*
2	4	2	50
3	9	3	67
5	25	5	80
10	931	10	99

* Including self-pollinations.
Note: These figures are based on the assumption that the groups are represented by equal numbers in the population.

In the case of systems in which fertile crosses are very highly fertile, and incompatible crosses are very incompatible, fertility would follow bimodal distributions. In perfect systems the two modes would be represented by straight lines. In actual practice, genes of minor effect usually widen out the curves without destroying the bimodality. But the fertility curves of the sweet potato are not bimodal Instead, they suggest that the plant is partially sterile, and that self-incompatibility plays a minor role in the fruit setting picture. Nevertheless, there are reasons to believe that self-incompatibility is also important.

Up to the present time, investigators have tried to explain the poor fruit and seed set of sweet potato on the basis of self-incompatibility. The technique for studying incompatibility is simplicity itself. One takes a number of plants, 20 will do for a start, and crosses them in all combinations. On the basis of fruit and seed set, the crosses are divided into 2 kinds, fertile and incompatible. One then compares the plants to each other and decides which plants act alike. He tries to divide the plants into groups that are incompatible in crosses within the groups but fertile in crosses between groups. This is an old and fruitful technique, usually successful, and our present understanding of self-incompatibility has rested on the fact that one can usually judge between fertile and incompatibility classes, and that one can classify plants with similar behaviour. But this is only the first step. To understand the genetic control of incompatibility one must make crosses among selected cross-fertile individuals, test the compatibilities of parents and offspring, make further back-crosses and second generation crosses, and finally draw up an explanatory model of gene number and gene action. To understand the physiological control one must study pollen behaviour in fertile and incompatible matings, during the process of germination, tube growth, fertilization, and sometimes also the processes of ovule and embryo development. In the sweet potato, not all these steps have been systematically followed.

Now, when one has a fertility distribution such as one sees in sweet potato, how can one classify plants into groups ? In reality all the crosses are sterile or partially sterile. I believe the answer is that sweet potato data have been squeezed and juggled to fit preconceived models of the incompatibility system, and discrepancies have been overlooked or discounted. But it is worth our time, I believe, to see how others have dealt with these problems.

The Japanese geneticist Terao (1934) was the first to attempt to classify sweet potatoes into incompatibility groups. His classification was simple and straightforward, 51 varieties classified into 3 intra-incompatible, and inter-compatible groups. This system was expanded to include a 4th group by Nishiyama (1961) and later by Shinjo (1962). Finally, Fujise (1964) broadened the number of varieties classified and ended up with 8 groups. Hernandez and Miller (1964), and Wang (1964) followed the system in classifying American varieties into 6 groups. Van Schreven, on the other hand, classified her varieties into 6 groups but the groups had some very different crossing relationships. Some of her crosses did not fall into strictly intra-incompatible and inter-compatible classes. Without exception, the published results of these investigators show internal discrepancies, such as fertility where incompatibility was expected, and incompatibility where fertility was expected. It must also be realized that judgment of fertility versus incompatibility was always made on a subjective basis. It could only be done in that fashion, for in all studies fruit and seed were distributed similarly.

I think the best evidence for the existence of a system of self-incompatibility in sweet potato is that similarities among varieties do exist, and these do make classification possible. But the incompatibility relationships are masked by a more powerful and generally-occurring sterility system.

Before leaving the subject of incompatibility classification, I would like to discuss the only attempts to my knowledge to study incompatibility in the sweet potato in the progeny of controlled crosses. As I have pointed out, without such crosses it is impossible to test models of genetic control of the behaviour. Van Schreven (1953) crossed two varieties of sweet potato, and compared the offspring to the parents (Table 3). She found 4 incompatibility groups among the offspring, two of which were like the parents and 2 of which were entirely different. It is interesting to note that the pattern of crosses found by Van Schreven almost duplicates the pattern of classification found in her varieties. Evidently, Van Schreven did not notice these resemblances, for she did not mention them, nor did she test the progeny against non-parental varieties.

Table 3.—Crossabilities of sweet potato varieties, and a family of seedlings (Van Schreven, 1953)

Varieties as females	Varieties as males: I and II	III	IV	V	VI
I and II	Some Fertile	Yes	Yes	Yes	Yes
III	Yes	No	No	No	Yes
IV	Yes	No	No	Yes	Yes
V	Yes	No	Yes	No	Yes
VI	Yes	Yes	Yes	Yes	No

Seedlings as females	Seedlings as males: A	B	C	D
A	No	No	No	Yes
B	No	No	Yes	Yes
C	No	Yes	No	Yes
D	Yes	Yes	Yes	No

I have constructed a simple genetic model to explain these results. The model depends on principals of gene action known to occur in other incompatibility systems. It suggests that incompatibility is controlled by two pairs of genes, of the so-called *Primula* type. Each dominant gene is epistatic to the recessive allele of the other. Or to express the system more clearly, each type of plant is incompatible with plants of the same genotype. In addition, the cross-compatibility or incompatibility between plants is determined by the dominant genes present. All crosses are fertile except those that have even one dominant gene in common.

Unfortunately, this model cannot be tested, for Van Schreven did not carry the studies through another generation.

A second attempt to classify the incompatibilities of progeny from controlled crosses was made by Fujise (1964). Working with the groups first delimited in Japan, he classified for incompatibility the progeny from crosses among the A, B and C types (Table 4). This table indicates the 3 kinds of crosses and the kinds of progeny actually obtained from each cross. You will immediately note that some crosses are within incompatibility groups where successful crossing would not be expected. But as I explained, in sweet potato the incompatibilities are seldom absolute, so that by making lots of pollinations eventually some seeds can be obtained in most crosses. Fujise's model to explain these results is extremely complicated and will not be fully explained here. The model assumed 3 loci, each with 2 or 3 alleles. The epistatic relations vary among the alleles, and some alleles only reduce or weaken the incompatibility. I am certain that this hypothesis will not hold up, especially as a more conservative hypothesis can be developed.

Table 4.—Progeny of crosses among A, B, and C varieties, according to Fujise

Parents	Type of Cross	Possible Progeny
A x A	Pseudo compatible	A, B, C
B x B	,,	B, C
C x C	,,	C
A x B	Compatible	A, B, C
A x C	,,	A, B, C
B x A	,,	A, B, C
B x C	,,	B, C
C x A	,,	A, B, C
C x B	,,	B, C

My model to explain Fujise's data is presented in the next table (5). This model has the advantage that it is based on only 2 genes of 2 alleles each. Weakened self-incompatibility is assumed to be due to other independent genes not a part of the specificity control system. The model depends upon a single epistatic action of one dominant gene *T*, over the other, *S*. Only when *T* is represented by its recessive allele does the *S* gene function. The model agrees with what we know about incompatibility in other plants. It is conservative and explanatory. Unfortunately, as in the case of the model designed to explain Van Schreven's data, no second generation or backcross data are available and thus the model cannot be tested. Finally, I would like to say that no model proposed can be easily extended to include other incompatibility groups. But I am not presently worried about such conflicts. I think we have not yet classified incompatibilities accurately enough to be sure of relationships. When we can be sure of relationships, we can construct models to explain the data, and then we can test them.

Table 5. A model that can explain Fujise's results

Parental combinations and possible genotypes	Genotypes and Classifications of possible progeny
A (Tt --) and A (Tt --)	A (Tt —), B (tt S-), C(tt ss)
B (tt S -) and B (tt S -)	B (tt S-), C (tt ss)
C (tt ss) and C (tt ss)	C (tt ss)
A (Tt --) and B (tt S-)	A (Tt —), B (tt S-), C(tt ss)
A (Tt --) and C (tt ss)	A (Tt —), B (tt S-), C(tt ss)
B (tt S -) and C (tt ss)	B (tt S-), C (tt ss)

Now I must confess that so far I have not told you much about my own work. I have proceeded on the assumption that the poor seed-setting behaviour of sweet potato is due to both sterility and incompatibility, and that one system cannot be worked out without also considering the other. So I have taken a completely different approach. Although we are crossing sweet potatoes, and trying to classify varieties, our principal objective has been to see what happens after pollination occurs. Thus, we have used various fixing and staining techniques in order to allow us to trace the pathway of the pollen through the female tissue.

These studies have revealed a great deal to us. Before I tell you what we found I need to tell you something about the structure of the pistil. The female organ is so normal or typical in structure that it could actually serve as a model for flowering plants in general. The floral parts are the stigma, the style and the ovary.

The stigma consists of two adjacent spherical bodies, each about 1 mm. in diameter, mounted on a slender tapering style, 0.4 — 1.2 mm. in diameter and 10 to 25 millimeters long. Each spherical lobe actually consists of 50 to 75 radiating branches from a central core. The branches are covered with papilionaceous cells, and the cells exude a sticky substance. In our trials, pollen grains adhered to the surface of the stigma by mechanical entrapment among the branches of the stigma, and by surface tension of the viscous exudate.

The main body of the stigma is composed of large, spherical or ovoid cells arranged in columns radiating from the stigma-style juncture to the branches. Branches completely cover the tissue core. Each consists of 25-75 files of parenchymatous cells which appear to be continuous with the files in the body of the stigma, and these in turn are continuous with the files of cells in the central core of the style.

In favourable transverse sections files of cells may be traced from stigma branches, through the stigma body, to the central core of the style. However, the cells of the style core are much smaller in diameter than the cells of the stigma. Thus, the stigma-style junction is characterized by a series of intergrading cell sizes where the files of cells from the branches pass to the style. Rough counts of cell numbers in stigma versus style suggest that in addition to increased cell size, more files of cells occur in the stigma than in the style.

The boundary between the parenchymatous cells of the stigma, and the papillae of the epidermis is strongly defined by heavier cell walls.

The epidermis of the stigma is composed entirely of dumbell-shaped papilionaceous cells. These cells are large (60-110 microns in length), and typically consist of a definite base, a constricted region, a broadened region, and a narrow nipple. The nucleus is usually in the broadened portion of the papilla. A distinctive feature of these cells is the prescence of numerous spherical particles. Larger particles (4-6 microns in diameter) are often grouped around the nucleus whereas smaller particles are dispersed through the cytoplasm. Haematoxylin staining suggests that larger particles are plastids, whereas the smaller particles may be mitochondria. In contrast, the parenchymatous cells are not so rich in particles.

The central part of the style consists of a pollen tube conducting tissue of long, narrow cells. This column of cells is of uniform size throughout the length of the style. The surface of the style is covered with a uniform epidermis. Between the epidermis and the conducting tissue is a layer of collenchyma which tapers in thickness from the style-ovary junction to the junction of stigma and style. Two bundles of xylem and phloem are imbedded in the collenchyma.

The juncture of the style and ovary can only be traced satisfactorily through serial sections. As the style enters the ovary, it becomes continuous with the septum dividing the two locules of the capsule. The central core of conducting tissue begins to spread laterally at the base of the septum, and is widest at the point of juncture with the ovules. Each ovule is attached to the placenta by a short funicular strip, which also delimits the micropyle. Part of the tissue of the funicular strip appears similar to and is continuous with the pollen tube conductive tissue, of the style. This cell type can be traced from the style to funiculus, to base of the ovule, through the integument of the ovule, upwards and over the upper part of the ovary, and down again to the region of the egg.

Upon germination, the tubes pass through the cuticle, between cells of the epidermis, through the region of thickened cell walls, and between the cells of the parenchyma, crushing cells to the side as they pass through. Old pollen tubes in the stigma are completely filled with callose. As the tubes pass into the style, they are confined to the central core of conducting tissue. The passage of 5 to 10 tubes through this tissue results in an obliteration of cell outlines, possibly through enzymatic breakdown of cell walls, and also by lateral pressure from the tube itself. The amount of callose within the tube varies from little or none, to irregular masses or complete plugs. Pollen tubes are not necessarily circular in cross section. Evidently the first tubes to pass through the style are crushed or distorted by the passage of later tubes.

Within the ovary, the tubes follow the circuitous path of the conducting tissue.

We are now in a position to talk about what happens after pollination. Togari (1942) observed some years ago that pollen fails to germinate on the stigma of the sweet potato after self-pollination. It has been assumed since then that the physiological basis for self-and cross-incompatibility in the sweet potato is pollen germination failure. Togari used these observations in a re-classification of the Japanese self-incompatibility groups and came up with essentially the same results as Terao, namely that Japanese varieties could be divided into 3 intra-incompatible, inter-compatible groups His final analysis showed almost complete pollen germination failure after self-or after within-group cross-pollinations. But problems were encountered in the crosses between groups. To use his words, "Even in the compatible crosses there exist remarkable variations in regard to the percentage of pollen germination as well as the growing velocity of pollen tube." To explain this behaviour, Togari postulated other properties directly related to the incompatibility group. These assumptions are that the germinability and growing rate of the pollen tubes were controlled by the same genotype as that which gave group specificity, and that the three groups differed with respect to the strength of these processes. He also postulated that the groups differed in the strength of the stimulus to germination provided by the style. I think all investigators would agree that the physiological system of incompatibility depends on pollen germination failure. Likewise, it is certain that pollen germination is restricted even in fertile matings. But Togari's conclusions with respect to group differences have not proved accurate and in later studies have been discounted. I think the problem here is that pollen germination failure is due in some cases to sterility rather than incompatibility. I shall come back to this point when I try to draw up a new theory for the poor fruit set of the sweet potato.

We have looked at thousands of sweet potato styles and have counted the number of pollen grains on the stigma, the number of tubes in the stigma, and the number of tubes in the style. These counts serve as fertility indices, and we can graph their distribution in the same manner that we graphed the distribution of fruit and seed setting data (Table 6). It is very interesting to see that the curves representing distribution of tubes per stigma and tubes per style not only have the same shape, but their shape is exactly the same as those of fruit and seed set distribution. Just as we concluded that lack of bimodality of fruit and seed setting distribution curves represented sterility instead of incompatibility, we must now admit that these two new indices are also indices of sterility. What I am saying is that failure of pollen to germinate is one of the characteristics of sterility in the sweet potato. This does not contradict the hypothesis that the mechanism of self-incompatibility is also pollen tube failure. But any particular example of pollen germination failure cannot arbitrarily be considered as due to incompatibility, for sterility of varying degrees will always be present.

Table 6. Distribution in numbers of pollen tubes in stigma and in style after crossing

Pollen tubes in stigma Tubes per stigma	Number of crosses	*Pollen tubes in style* Tubes per style	Number of crosses
0.0	72	0.0	111
0.01 — 3.0	100	0.01 — 0.40	70
3.1 — 6.0	54	0.41 — 0.80	45
6.1 — 9.0	44	0.81 — 1.20	39
9.1 — 12.0	27	1.21 — 1.60	44
12.1 — 15.0	12	1.61 — 2.00	16
15.1 — 18.0	11	2.01 — 2.40	4
18.1 — 21.0	7	2.41 — 2.80	3
21.1 — 24.0	2	2.81 — 3.20	0
24.1 +	3	3.21 +	2

But what about after pollen germination? What happens next? I have already described the pollen tube pathway through the stigma, style and ovary. Because we had reason to believe that some seedless crosses were nevertheless characterized by excellent pollen germination, we made a study in which the pollen tubes in the stigma, and in upper, mid, and lower style were counted and compared to the number of seed actually set in the fruit. This study was very rewarding (Table 7). It can be seen from the table that in both a fairly fertile cross, A, and a fairly infertile cross, B, that there is a drastic reduction of numbers in pollen tubes between stigma and style. Within the style there is no statistical difference in number of tubes in the various regions. But in both crosses many more pollen tubes are found in the style than seeds are produced in the ovary. We have seldom seen pollen tubes in the ovary, but I believe some pollen tube elimination does take place between style and ovule. Thus, from these data and many, many other observations of hundreds of crosses I am forced to conclude that the reproductive potentiality of sweet potato is limited by reduction in number of pollen tubes between stigma and style, and between style and ovule.

Table 7. Pollen tube growth and fruit set in two sweet potato crosses

Cross	Pollinations	*Pollen Tubes* Stigma	Upper style	Mid style	Lower style	% capsule Set	Seeds per pollination
A	42	19.6	6.1	5.7	5.0	42.8	0.86
B	94	16.1	0.92	0.74	0.61	6.4	0.10

Yet some tubes do find their way to ovules and some seeds are set, but fertilization does not finish the story. Sweet potato fruits seldom contain more than one seed, but if one determines from a series of pollinations and subsequent fruit set data the probability that a single ovule is set, one can then determine the expected frequency of occurrence of fruits of 2, 3 or 4 seeds. This we have done, and we find that seed set is at random, with a low probability at best that any particular ovule grows to be a seed. What happens to the rest of the ovules? To determine this we have observed the development of ovules in the ovary and found two distinct developmental rates. Some ovules enlarge only a small amount, while others grow rapidly. These differences result in the production of two kinds of products at maturity, which I believe, come from unfertilized ovules, and seeds. The distribution of weights of ovule products from a good number of fruits from which all 4 products were obtained is given in the next table (8). You can clearly see that two kinds of products are produced, with absolutely no overlap. When one tries to germinate the seed, one finds that smaller seed do not germinate well, and in fact, there is a rather strong line of demarcation between the 50 per cent of the seeds that germinate and the 50 per cent that do not. I interpret these data to mean that most ovules are not fertilized, and of those that are, only about half produce embryos sufficiently viable to germinate. Herein one sees two more signs of sterility.

Table 8.—Distribution of sizes of mature seed and aborted ovules of sweet potato, with respect to germination

Weight of seed or ovule (mg.)	Number of examples	Percentage germinated
0.0 — 0.5	329*	0.0
1.1 1.5	15	0.0
1.6 3.0	17	0.0
3.1 7.0	12	0.0
7.1 11.0	17	11.7
11.1 15.0	34	29.6
15.1 19.0	35	68.6
19.1 23.0	40	97.5
23.1 27.0	16	100.0
27.1 31.0	5	100.0

* The average weight of these scales was about 0.02 mg.

But sterility does not stop at that point. We have grown sweet potato populations and find that as many as 10 per cent of the plants are small, weak, spindly, and ready to die. These we do not plant in the field. In field plantings, we find that perhaps another 10 per cent of the plants are weak, unproductive, easily killed or crowded out.

I think now I can synthesize the sterility story for you (Table 9).

Table 9. Characteristics of sterility in sweet potato.

1. Some pollen germination failure.
2. Disorientation and failure of some pollen tubes to pass from stigma to style.

3. Disorientation and failure of some pollen tubes to pass from style to ovule.

4. Production of some poor seed.

5. Production of some poor plants.

The cause of the sterility problem lies in the nature of the sweet potato itself. It is a hexaploid with 90 chromosomes. Although chromosomes pair normally, considerable secondary association occurs, indicating that partial homology exists among the genomes constituting the sweet potato. Thus gametes may not always carry a well balanced set of chromosomal material. Poor germination of seeds and weakness of seedlings are probably due to such imbalances. Although much more difficult to document, it is highly probable that a large portion of gametes produced by any sweet potato variety are weak or imbalanced. Such weakness could be expressed during critical growth phases of the pollen tube.

In the path of the pollen tube are three critical areas. The first is the surface of the stigma, and many pollen grains fail to pass this obstacle even in fertile matings. The second obstacle is the stigma-style juncture where the pollen tube pathway is suddenly and drastically restricted. A change in pollen-tube physiology probably occurs at this point. The third obstacle is the style-ovary juncture where the pollen tube pathway becomes irregular and less well-defined. We venture the hypothesis that the sterility barriers of the sweet potato are no more than the sites or processes where weak or inadequate gametes are eliminated. Elimination may occur for mechanical or physiological reasons either before or after pollination or fertilization. We also hypothesize that these weaknesses are general in occurrence, multigenic in control, and can only be corrected by a long period of mass selection for fertility.

I think now that we understand a little better the sterility, that we shall soon be able to put together a unified theory of the incompatibility. Some of the facts and suppositions are summarized in Table 10. We are interested in and working with both the genetic and physiological aspects of this problem. From the genetic point of view we have three programmes in progress. The first programme is a study of self-incompatibility in a diploid species of *Ipomoea*. This species was selected from 11 self-incompatible species found in a survey of the family Convolvulaceae. Because of its diploid status and high fertility, we expect to find a simple system of incompatibility not masked by sterility. We have completed 3 generations, and expect to finish the job with confirming generations in 1967-68. We have already made some interesting progress, and can predict that the analysis of this system will help us understand and interpret the system in the sweet potato.

Table 10.—Some characteristics of the self-incompatibility of the sweet potato

Characteristic	*In sweet potato*
Floral morphology	—Homomorphous
Site of inhibition	—Stigma
Nuclei of pollen	—Two or three ?
Pollen cytokinesis	—Simultaneous
Loci involved	—Two or three ?
Alleles per locus	—Two or more ?
Site of control	—Sporophyte
Number of groups	—Low (4-8)
Gene action, pollen	—Dominance & epistasis ?
Gene action, stigma	—Dominance & epistasis ?

A second study is of the incompatibility groups in 28 varieties we have collected. We have crossed these in as many combinations as possible, and have developed statistical indices of the degrees of resemblance among them. With these data we expect to eliminate a good part of the human errors of judgment. The analysis should be finished this spring or summer. We have progressed far enough to recognize another of the basic reasons for poor fruit set in North America. It is simply that most varieties belong to the same incompatibility group.

The third genetic study concerns the control of self-incompatibility in the sweet potato itself. For the study we have selected as parents some clones with rather strong self-incompatibility, but better than average cross-fertility. The backcross generations are now in the field waiting for our tests, and we will try to complete the analysis in 1967-68. With the completion of these 3 programmes, I think we shall have the essential facts concerning genetics of the phenomenon.

But questions regarding the physiological control remain. The specialized structure of the papillae of the stigma is suggestive of the role these cells must play in the incompatibility reaction. Exudate on the stigma comes from the papillae, and this could be rich in enzymes or inhibitors. We do not yet know whether sweet potato pollen has the ability to grow on stigmas in general, is actively inhibited from growing on some, or whether the pollen lacks the ability to grow on its own stigmas unless it is stimulated. I believe we can get useful information on this subject by a series of experimental pollinations including such treatments as double pollinations, transfers of pollen from one stigma to another, mutilation of the stigma, collection of stigmatic exudates on agar, etc. We would also like to examine the enzymes of the stigma histochemically, if possible. Especially, we would like to know if the stigma has a cutin and the pollen a cutinase system. These are characteristic of all other incompatibility systems in which pollen fails to penetrate the stigma. Preliminary tests suggest that the incompatibility of sweet potato does not depend on a cutin-cutinase system, and thus may be unique.

A final task that we would like to be able to do is to use serological techniques to actually discriminate between different incompatibility substances. With such techniques we could identify incompatibility groups without the necessity of cross pollinations. A visionary task, perhaps, but something that has recently been done successfully at Cornell with the family Cruciferae.

To conclude, I would like to say that untangling the relationships of incompatibility and sterility in sweet potato has been a fascinating pastime. The sweet potato has proved to be an excellent example of an imperfect species, a species in which evolution has not yet straightened out the reproductive processes and in which sex is thus only a second-best method of reproduction.

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NOTES ON SELF-INCOMPATIBILITY IN THE GENUS *IPOMOEA* L.

—*by*—

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The existence of self-incompatibility and the associated phenomenon of cross-incompatibility in the sweet potato (*Ipomoea batatas* (L.) Lam.) has long been recognised (Mendiola, 1921; Stout, 1926; Tioutine, 1935; Togari *et al.* 1942; Poole, 1952). In a breeding programme, one of the important effects of incompatibility is to reduce the potential genetic base available for the generation of seedling populations on which selection for improved types can be practised. Self-incompatibility also precludes or narrowly restricts the use of conventional techniques of parental evaluation such as progeny testing and it retards fixation of desirable heritable characters because it so severely limits inbreeding.

An investigation of the various aspects of the floral and reproductive biology of the species in question is the traditional approach to the study of incompatibility in plants. The important morphological, physiological and genetic features normally implicated in the manifestation of self-incompatibility, have been reviewed by Pandey (1960). Martin (1965) has adequately reviewed this subject in the sweet potato within such a framework. With the exception of the sweet potato, the authors know of no reported investigations of the phenomenon of self-incompatibility within the Convolvulaceae.

By elucidating and describing more precisely the nature of the mechanism of genetic control of incompatibility, attempts to catalogue the characteristics associated with the expression of incompatibility in a crop species such as the sweet potato could be expected to permit a more meaningful approach to the establishment of breeding programmes. The present study was directed towards obtaining a better understanding of incompatibility in the sweet potato by examining (i) the relationship between heterostyly and fertility, (ii) cross-compatibility relations among cultivars and by (iii) a preliminary survey of the characteristics of the incompatibility reaction in two wild species of *Ipomoea*. The outcome of interspecific crosses among the three species was also examined.

MATERIALS AND METHODS

Twenty West Indian sweet potato cultivars, selected as parents in the U.W.I. breeding programme, and two wild species, *Ipomoea trichocarpa* Ell. and *Ipomoea gracilis* R., comprised the main plant materials used in the present study. Seeds of the wild species were obtained from Dr. G. Chapman of the Department of Botany, U.W.I., Jamaica, from a collection he made in Mexico. Dr. Chapman's identification of these species has been tentatively accepted because confirmation of their identity has not yet been secured. In particular, the legitimacy of the name *I. trichocarpa*, as Shinners (1962) has pointed out, is still in doubt. The somatic chromosome number of *I. trichocarpa* was determined to be $2n = 30$. Its type locality is listed as Carolina and it is reported to be distributed throughout tropical America (House, 1908). Chapman and Wedderburn (1966) reported that *I. gracilis* was also a diploid ($2n = 30$) but the authors were not able to confirm this. The distribution of I. *gracilis* is said to be circumtropical although most reports of the species have come from the tropical American and Caribbean areas (House, 1908).

Three plants of each of the wild species (designated as IT or IG 1, 2, or 3) were raised from seed and reciprocal intra- and inter-specific pollinations made among them. The sweet potato cultivar C26 was also crossed with these plants, as a pollen parent. For a preliminary survey of the segregation of incompatibility phenotypes, ten plants representing progenies from each of the six families derived from all possible combinations of the three parent plants within each species (reciprocals being counted separately) were raised. Analysis of the cross IT (1) x IT (2) and its reciprocal was the most complete at the time of writing and details of only these results will be presented.

Cross- and self-pollinations within the set of 20 sweet potato cultivars were started in 1964 and have been continued since then.

In the determination of incompatible matings, two methods were employed. First, incompatibility reaction was determined as the number of seeds set per flower crossed or selfed. In crosses among sweet potato cultivars, variation in intensity and duration of flowering very often prevented the use of the same number of flowers within each parental combination. Accordingly, estimates of self-fertility were based on totals of 20 to 97 flowers and estimates of cross-fertility on 20 to 160 flowers manipulated. In the wild species, seed-set was based on 100 to 500 flowers in the case of crosses among the original parents and on 10 to 20 flowers in the case of their progenies.

The second method of defining incompatibility reaction was based on *in vivo* tests of pollen germination on stigmas and pollen tube penetration into the style at intervals ranging from 3 to 24 hours after pollination. At least five pistils from each cross were used for this assessment. Pistils with ovaries removed were examined by a rapid squash technique. In addition, whole pistils from selected crosses were reserved for detailed histological investigation. The study of all microtome sections has not been completed and results of *in vivo* tests presented in this paper are largely confined to data on incompatibility reaction as determined from pollen germination on stigmas.

A sample of ten flowers per cultivar was used to determine stamen lengths in the sweet potato. Measurements of length were made from the point of insertion of these organs in the floral receptacle.

RESULTS

Heterostylic variation and fertility in the sweet potato

Among crosses between sweet potato parent cultivars, seed set data from 26 compatible combinations were available for the present analysis. Pistil length of female parents ranged from 16.6 mm., to 22.9 mm., mean stamen length of male parents ranged from 10.9 mm. to 17.7 mm.; (Table 1).

Table 1. Features of heterostylic variation in a sample of 20 sweet potato cultivars.

Character	Mean (mm.)	C.V. (%)	Range (mm.)
Pistil length	20.0	9.4	16.6 — 22.9
Stamen length	15.5	12.5	10.9 — 18.9
Elevation of stigma over stamen	4.5	52.8	0.9 — 7.7

An analysis of the correlation between female fertility and the mean difference between pistil length of the female and mean stamen length of the male was performed. The correlation coefficient ($r = 0.26$) between them did not attain significance at the five per cent point.

Intra-incompatible, inter-compatible groups in the sweet potato

On the basis of seed set and *in vivo* determinations of pollen tube germination on the stigma, cultivars were found to fall into four intra-incompatible, inter-compatible groups (Table 2). The pattern of distribution of fertility of matings was the typical hyperbolic-type curve with higher frequencies skewed toward the zero and low fertility classes and progressively diminishing frequencies in the higher fertility classes with truncation in the vicinity of the class interval centred at 2.0 seeds per flower. Forty-three point eight per cent of all matings set no seed ; of the remaining matings which set seed, fertility ranged from 0.1 to 2.0 seeds per flower. All cultivars were self-incompatible and in matings within intra-incompatible groups, there were only two instances of crosses which set viable seed. A common feature of crosses between groups was the existence of substantial differences in reciprocal fertility. In particular, cultivars of group I crossed as female to cultivars of group II were, on the average, more fertile than their reciprocals. At least three clear instances of unilateral incompatibility were established. In such combinations, matings compatible in one direction were totally incompatible in the other.

Compatibility relations in intra- and inter-specific crosses and their progenies.

The cytology of pollen reaction on stigmas and pollen tube growth in styles was substantially similar in the three *Ipomoea* species investigated. Some results of detailed observations carried out in the sweet potato are presented in Table 3.

In incompatible pollinations, the mean number of pollen grains retained on the stigma was 50.7. The number of abnormal pollen grains observed in these matings was very low and pollen germination was negligible. In these matings, no penetration of pollen tubes into the style was observed. In compatible matings, on the other hand, the mean number of pollen grains retained on the stigma was approximately 107. The percentage of abnormal pollen grains was again negligibly small. The mean number of germinated pollen grains per stigma was 16.2 with a range from 2 to 40 and the mean percentage of germinated pollen was 14.8 with a range from 2.5 to 42.2.

Table 2 Sweet potatoes: Intra-incompatible, cross-compatible groups

♀ \ ♂		G I							G II						G III		G IV
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
G I	1	−	−	−	−	−	−	−	+	±	−	+	±	+	+	+	
	2	−	−	−	−	−	−	−	±	+	−	+	±	±	±	±	
	3	−	−	−	−	−	−	−	+	±	+	±	−	+	+	+	+
	4																
	5	−	−	−	−	−	−	−	±	−	±	+	±	−	−	+	±
	6	−	−	−	−	−	−	−			+	−	+			+	
	7	−	−	−	−	−	−	−	±	−	−	+	+	−	±	+	−
G II	8	±	±	−	−	±	±	±	−	−	−	−	−	±	−	±	±
	9	−	+	±	±	+	−	+	−	−	−	−	−	−			
	10				−		±				−			−	+	+	
	11	±	±	±	−	±	±	−	−	−	−	−	−	−	±	+	
	12					+							−		+		
	13	−	±	±	±	+	±	±	−	−	−	−	−	−	±		±
G III	14			+		+		±						+	−		
	15			±	±	±	±	±			±	±	−	±	−	−	
G IV	16	−	±	+	−	+	−	−	±	−	−	+	+	+	+	+	−

− Fertility 0.00 – 0.10 seeds per flower
± " 0.10 – 0.20 " " "
\+ " > 0.20 " " "

Table 3. Comparative pollen germination and penetration into style : Sweet potatoes

Type of Cross	$\bar{x}$	C.V. (%)	ABN (%)	POLLEN GRAINS ON STIGMA GERMINATING $\bar{x}$/Stigma	Range	$\bar{x}$ %	Range
Compatible	107.3	29.0	1.1	16.2	2 — 40	14.8	2.5 - 42.2
Incompatible	50.7	44.6	4.0	—	—	0.1	—

POLLEN TUBES IN STYLE		$\bar{x}$	Range	Modal Class (% Freq.)	Range of Modal Class
Compatible	Top	6.9	2 — 21	32.7	4 — 6
	Mid	3.9	1 — 10	25.7	2 — 3
	Lower	1.3	0 — 5	55.4	0 — 2

In the lower part of Table 3 details of pollen tube penetration into upper, mid and lower style are presented. A decreasing trend in the mean number of pollen tubes observed at each stylar level was noted. The range in the number of pollen tubes observed at top- and mid-style is fairly wide and may more appropriately be taken as being representative of the variation in the lower limits of pollen tube density observed in these crosses. In most cases more pollen tubes than were observed were probably present, but the squash technique employed coupled with the intermittent attenuation and sinuous growth of pollen tubes in the style prevented more accurate determinations. In compatible matings, four to six pollen tubes were most frequently observed in the upper portion of the style; corresponding ranges for mid and lower style were 2-3 and 0-2 pollen tubes, respectively.

Fertility relations in intra- and inter-specific crosses involving *I. trichocarpa*, *I. gracilis* and *I. batatas* are presented in Table 4. The three parental clones of *I. trichocarpa* and *I. gracilis* were self-incompatible. Cross combinations within each species were mostly fertile but in some parental combinations, differences in reciprocal fertility of about 50 per cent were noted. In the cross IG (3) x IG (1) there was an indication of unilateral incompatibility : IG (3) x IG (1) set 0.76 seeds per flower while the reciprocal cross had a seed-set of 0.1 seeds per flower

Table 4. Fertility relations (seeds/flower) in intra- and inter-specific crosses : I. trichocarpa, I. gracilis and I. batatas

♀ \ ♂→	IT (1)	IT (2)	IT (3)	IG (1)	IG (2)	IG (3)	IB (1)
IT (1)	0.00	1.43	1.05	0.00	0.00	0.00	0.00
IT (2)	0.53	0.00	0.43	0.00	0.00	0.00	0.00
IT (3)	0.94	1.06	0.00	0.00	0.00	0.00	0.00
IG (1)	0.13	0.13	0.00	0.00	1.14	0.01	0.07
IG (2)	0.02	0.05	0.08	0.52	0.00	0.60	0.00
IG (3)	0.11	0.04	0.07	0.76	1.05	0.00	0.23

In inter-specific crosses between *I. trichocarpa* as female and *I. gracilis* as male, no seed-set occurred. In the reciprocal combinations, however, seed-set ranged from 2 to 13 per cent. Two inter-specific hybrid plants from the cross IG x IT were tested as male parents against a number of sweet potato cultivars: Pollen germination and penetration into the stigma was noted in four such combinations. Cultivar C26 (*I. batatas*) as a pollen parent stimulated normal capsule development in IG (1) and IG (2) of 7 and 17 per cent, respectively. Seeds from these crosses were shrivelled and failed to germinate. No such stimulation occurred when *I. trichocarpa* was used as female parent.

Histograms of fertility of balanced matings among progenies of families within *I. trichocarpa* and *I. gracilis* are presented in Figure 1. In both cases the skewed distribution of fertility reminiscent of the distribution of fertility in the sweet potato was clearly evident. In *I. trichocarpa*, truncation of the curve was at a seed-set value of 4.0 seeds per flower; in *I. gracilis* the range of fertility was narrower and truncation was at a fertility of 1.5 seeds per flower.

In the determination of incompatible matings in cross combinations among progenies and parents in families of *I. trichocarpa*, a number of discrepancies were found between the seed set and *in vivo* methods of establishing incompatibility reaction. Table 5 presents results of an analysis of the comparative efficacy of these two criteria in differentiating alternative mating types.

Table 5.—Comparison of two methods of determining incompatibility reaction in matings among progenies of I. trichocarpa.

	Unadjusted	Adjusted
No. assessed alike	244	232
No. assessed differently	40	52

Computed $\chi^2 = 1.57 <$ Critical $\chi^2 = 3.84$, $P = 0.05$

When matings assessed as incompatible included only those in which absolutely no seed-set occurred, the percentage of mis-classification was 18.3 When this restriction was removed and matings with less than ten per cent seed set were included in the incompatible class, there was a reduction in mis-classification to 14.1 per cent. This reduction, however, did not represent a significant gain from this adjustment.

The ratio of incompatible to compatible matings was also affected by the criteria of assessment.

In Table 6 results of the analysis of this ratio are presented. When incompatible matings were unadjusted, there was a significant departure ($P = 0.5$) from the 1 : 1 ratio with both methods of assessment of incompatibility reaction. When incompatible matings were adjusted to include crosses which did not exceed 10 per cent seed set, the departure of the ratio of incompatible matings to compatible matings from the hypothesised 1 : 1 ratio was not significant at the five per cent level.

Fig. 1 Histograms of Fertility (seeds/flower)

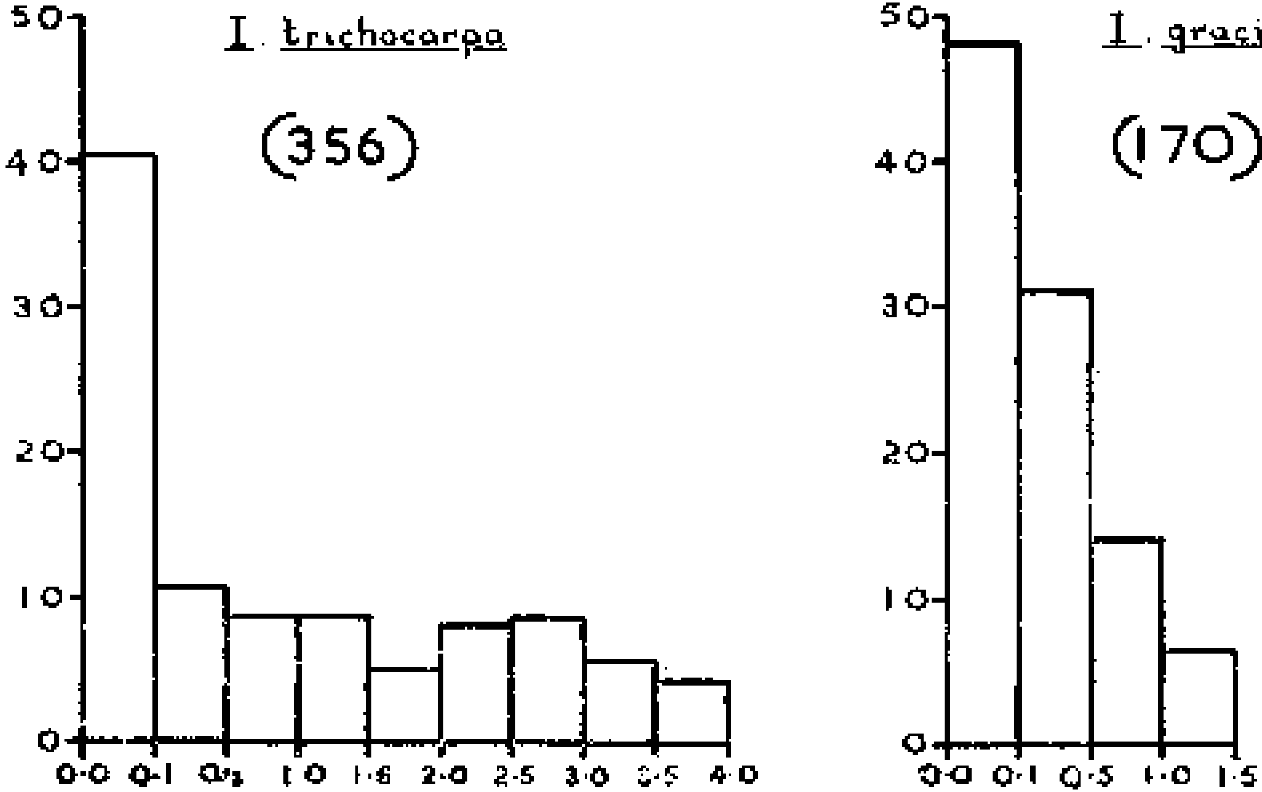

Table 6.—Comparison of ratio of incompatible to compatible matings in families of I. trichocarpa in relation to method of determination of mating type.

Unadjusted

Method of determination	Type of Mating —	Type of Mating +	TOTALS
In vivo tests	111	173	284
Seed Set	134	150	284
TOTALS	245	323	

Computed $\chi^2 = 14.0$ Tabular $\chi^2 = 3.84$ at $P = 0.05$

Adjusted

Method of determination	Type of Mating —	Type of Mating +	TOTALS
In vivo tests	142	142	284
Seed Set	133	151	284
TOTALS	275	293	

Computed $\chi^2 = 1.02$ Tabular $\chi^2 = 3.84$ at $P = 0.05$

The relatively high incidence of misclassification of incompatibility reaction among these matings did not substantially affect the identification of incompatibility phenotypes among progeny of the crosses IT (1) x IT (2) and its reciprocal. This was due to the fact that it was fairly easy to determine, by inspection, the consistency of crossing behaviour within a set of plants provisionally assessed alike with regard to incompatibility reaction by either criterion.

In Table 7 a tentative summary of the distribution of incompatibility phenotypes in the family IT (1) and IT (2), mainly on the basis of seed set, but supplemented by *in vivo* tests of compatibility reaction of pollen on stigmas is presented. The relatively small number of flowers used for estimates of seed set and the fact that *in vivo* tests were restricted to examination of pollen reaction on the style only, may have resulted in an inadequate assessment of the possible significance of some observed cases of zero or low seed-set and differences in reciprocal fertility which were judged compatible by the *in vivo* method. The results presented in Table 7, therefore, must be regarded as a first approximation to a relationship which might be much more complex.

Table 7.—Incompatibility relations among incompatibility phenotypes in family IT (1) x IT (2) and IT (2) x IT (1)

♀ \ ♂→	IT (1)	IT (2)	(1 x 2) A	(1 x 2) B	(2 x 1) A	(2 x 1) B
IT (1)	—	+	—	+	—	+
IT (2)	+	—	+	—	+	—
(1 x 2) A	—	+	—	+	—	+
(1 x 2) B	+	—	+	—	+	—
(2 x 1) A	—	+	—	+	—	+
(2 x 1) B	+	—	+	—	+	—

DISCUSSION

Heterostylic variation and fertility in the sweet potato

Heterostylic variation has a wide distribution in the plant kingdom, occurring in some 15 orders (Ford, 1964). In species of the genera *Primula* and *Lythrum*, heterostyly is intimately integrated with the expression of incompatibility through closely linked blocks of genes which control anther height, style length, rate of pollen tube growth together with pollen size and length of stigmatic papillae (Ernst, 1933 in Ford, 1964).

The existence of heterostylic variation in the sweet potato has been noted by several workers (Poole, 1952; Van Schreven, 1954; Yen, 1961). In his Pacific, Asiatic and tropical American collection of sweet potatoes, Yen (1961) encountered a range from extreme pin heterostyly to homostyly. Van Schreven (1954) considered that heterostyly was not associated with the expression of incompatibility in the sweet potato, apparently on the basis of observation. Martin (1965) pointed to the absence of supporting experimental evidence for this relationship and suggested that the extrorse dehiscence of anthers combined with their various levels may serve only to ensure good distribution of pollen on visiting insects.

The analysis of matings involving females of differing pistil and anther heights provide little evidence in support of the view that fertility in the sweet potato is related to heterostylic variation. In spite of this indication, however, the authors consider that the question of the probable association between heterostyly and—at least—fertility in *I. batatas* remains unresolved. This view is taken because of the wide variation in heterostyly encountered in this species.

In Yen's (1961) South American collection, pistil length varied from 17mm. to 26 mm. This range of variation was similar to that recovered in the present study (Table 1). In a randomly inter-breeding experimental population of seedling sweet potatoes, Jones (1966) found style lengths ranging from 8 to 29 mm. Considering that, under natural conditions, wilting and deterioration of the floral parts of the sweet potato flower are generally complete within 48 hours, the rate of pollen tube growth down the stigma and style would seem to be a critical factor in the potential for setting seed. It is not inconceivable, therefore, that the existence of differences of up to 21 mm. in pistil length among a set of cross-compatible cultivars, under natural conditions, could be of importance in determining whether the male gametes are delivered to the placental tissue before the onset of deterioration of the stigma and die back of the style.

In a large inter-breeding population in which representation of cultivars in cross-compatible groups is not limiting, the influence of differences in style length may be negligible. However, in small breeding blocks where there may be restrictions on compatible pollen sources, differences in pistil length could conceivably exert some influence on fertility. Differences in pistil lengths either independently, or in concert with the incompatibility mechanism, may very well be implicated in some cases of low fertility, differences in reciprocal compatibility and even unilateral incompatibility, in the sweet potato.

The fact that anthers are borne at different levels may be of significance in this context as well. In *Primula*, the level at which anthers are borne determines what the incompatibility reaction of the pollen will be. In *Lythrum*, where heterostyly has been further elaborated to feature three pistil and three anther levels, a similar relationship exists. Ford (1964) has pointed out that the genetic system controlling the heterostyle-polymorphism in such species, permits the reconstruction of the mating system from one that is primarily outbreeding to one that is mainly inbreeding, under certain conditions of stress. In *Primula*, this transition is accompanied by a transference from heterostyly to pin homostyly (Ford, 1964).

Yen's (1961) extensive study of variation in the sweet potato indicated that the range of variation of Asiatic and Pacific populations sampled for a number of characters including anther height and pistil length, was exceeded by the range in material from his South American collection. In particular, the range in pistil length in the Asiatic and Pacific collections was narrower than the range recovered in the South American collection. This feature may be nothing more than a reflection of the types of cultivars which were originally transferred to these areas or which may have been generated from a relatively small, initial source subsequent to its introduction. However, the frequently reported higher incidence of self-fertility particularly in Old World sweet potato cultivars, might possibly be indicative of a trend towards a change in the mating system analogous to that reported by Ford (1964).

Heterostyly, by itself, is a fairly effective means of ensuring out-breeding and in *I. batatas*, may no longer be under the control of the genetic system responsible for self-incompatibility. In fact, the sweet potato may well be a species in transition from an incompatibility system originally integrated with heterostyly to one in which heterostyly is now only a relict feature of floral morphology of dubious adaptive worth. On the other hand, this species may be one in which the evolution of an efficient incompatibility mechanism has been held in suspense through the mediation of domestication and vegetative propagation by man.

A critical experimental examination of the association between heterostyly and fertility is very difficult because of the peculiarities of this plant species. This fact, no doubt, may explain the absence of reliable information on its possible significance in the breeding system. The authors consider that critical studies on the significance of heterostylic variation in the sweet potato may yield important evidence, not only about its probable relationship with self-incompatibility, but also towards the elucidation of a number of unresolved questions concerning the centre of origin and pattern of distribution of this species.

Intra-incompatible, inter-compatible groups in the sweet potato

Apart from its obvious utility in a breeding programme, the establishment of intra-incompatible — inter-compatible groups could contribute important evidence on the probable mode of genetic control of the incompatibility mechanism.

The character of the distribution curve of fertility, the existence of reciprocal differences in fertility and the presence of unilateral incompatibilities observed in the present study, were substantially similar to those reported by other investigators working with similar material (Hernandez and Miller, 1962; Martin and Cabanillas, 1965). The number of cross-compatible groups found in other studies in the sweet potato, have been relatively few (Terao, 1934; Togari and Kawahara, 1942; Fujise, 1964, Hernandez and Miller, 1962; Martin and Cabanillas, 1965).

These characteristics of breeding behaviour in the sweet potato have already led Martin (1965) to conclude that self-incompatibility in this species is of the sporophytic type and probably under the control of a small number of genes. The presence of unilateral incompatibilities also suggests the existence of dominance relations among alleles involved in the control of self-incompatibility.

Compatibility relationships in intra- and inter-specific crosses and their progenies

The cytology of pollen reaction and pollen tube growth.

The cytology of pollen reaction on stigmas and pollen tube growth in the conductive tissue of the style was closely similar in the three *Ipomoea* species investigated.

The first feature of significance in pollen grain reaction on stigma was the fact that in matings which were clearly incompatible, approximately half the number of pollen grains was retained on the stigma as were retained in compatible matings (Table 3). Secondly, in incompatible pollinations, pollen grains failed to germinate. Similar findings by Van Schreven (1953) and Martin and Cabanillas (1965) identify the stigmatic papillae in these species as a major site of inhibition of pollen tube growth. Simultaneous cytokinesis during microsporogenesis have been reported in some *Ipomoea* species. There have also been reports that mature pollen grains in some species of this genus are trinucleate. The total evidence provided by these results endorses Martin's (1965) suggestion that self-incompatibility in the sweet potato is of the sporophytic type.

In figure 2, photomicrographs illustrate the sequence of pollen germination on the stigma and pollen tube penetration into the style in a compatible mating in *I. trichocarpa*. This pattern was fairly typical of fertile matings in the three species. The greater retention of pollen grains on stigmas in compatible crosses, was no doubt due to the mechanical retention afforded by germinated pollen tubes growing into the stylar tissue. Pollen tubes with swollen tips were frequently discerned in stigmas (Fig. 2A and D). There appeared to be some variation among matings assessed as compatible with regard to the number of advancing pollen tubes which had inflated tips. It was difficult to quantify such variability in cytological preparations of stigmas fixed six to seven hours after pollination, however, because of the massive congression of pollen tubes converging towards the stigma-style insertion.

The occurrence of pollen tubes with dilated tips is a feature of the incompatibility reaction in some self-incompatible species. Their regular occurrence in *I. batatas*, *I. trichocarpa* and *I. gracilis* points to the possible inadequacy of the *in vivo* method of assigning incompatibility reaction on the basis of pollen germination on the stigma alone. More importantly, however, it raises the issue as to whether these swellings represent a permanent termination of pollen tube growth and a consequent non-delivery of gametes to the ovules.

The stigmatic tissue is rapidly traversed by advancing pollen tubes (Van Schreven, 1953; Martin and Cabanillas, 1965). These tubes converge on the stigma-style insertion in a solid cone in which it was possible to count up to 40 tubes in favourable preparations in some combinations (Table 3). Although actual counts of the number of pollen grains placed on the stigmas in cross pollinations were not made prior to fixation, stigmas were pollinated to saturation in order to ensure that pollen availability was not limiting. The wide range in the percentage of germinated pollen grains, therefore, could be expected to relate to the character of the distribution curve of fertility reported in these species. In order to quantify this relationship more accurately, however, more critical studies need to be undertaken.

In a high proportion of compatible combinations, it seemed evident that the large number of pollen tubes converging into the stigmatic cone, could not be physically accommodated into the conductive tissue of the upper position of the style. The mean number of pollen tubes observed at this stylar level was 6.9 but the actual number was subject to wide variation (Table 3). It has been suggested elsewhere (Martin and Cabanillas, 1965) that mechanical impedance of pollen tube growth in the stylar tissue may constitute a barrier to pollen penetration into the style. In crosses in which high percentages of pollen tubes germinated on the stigma, the relatively large numbers observed entering the conductive tissue, in this investigation, was more than adequate to effect full fertilization of the four ovules characteristically present in these species. Pollen tubes with inflated tips similar to those encountered in the stigma, were found at all stylar levels but more frequently in the upper portion (Fig. 2E). In the upper style where pollen tube density was greatest, tubes with inflated tips apparently forced adjacent pollen tubes to arc around them (Fig 2E). In both crushed and microtome preparations this feature of pollen tube behaviour tended to accentuate the obstructing pollen tube tip (s) and, where reconverging pollen tubes disappeared from the plane of focus, sometimes gave the impression that a single, large swelling existed in the path of the pollen tube, or that the large swelling terminated the pollen tube(s).

Because of the irregular pathway followed by pollen tubes in their progress through the style, the authors were not able to establish whether the swellings observed on the stigma were identical to those encountered in the style. In a number of instances pollen tubes in the stigma and style appeared to dilate and then continue growth, but the limitations of the squash technique prevented more critical cataloguing of the regularity of this occurrence.

Inflated pollen tube tips in stigmas and styles, is an invariable feature of the cytology of pollen tube growth in *I. batatas*, *I. trichocarpa and I. gracilis*. It is remarkable, therefore, that this phenomenon does not appear to have been commented on before. Martin and Cabanillus (1965) made detailed investigations of pollen tube growth in relation to stigmatic and stylar anatomy in the sweet potato but failed to make explicit mention of this characteristic

The question of the possible biological significance of swellings in pollen tubes of these species has been alluded to above. The decreasing trend in the mean number of pollen tubes from upper to lower style was associated with a similar trend in the number of swellings observed in pollen tubes. This constitutes strong circumstantial evidence that these inflations, at whatever level they occurred, might well represent sites of gametic extinction. Martin and Cabanillas (1965) have proposed that elimination of gametes occurs in compatible matings in the sweet potato but they have suggested that this is due to the failure of tube growth of pollen grains containing weak or unbalanced gametes. These investigators did not appear to relate gametic elimination to type of pollen tube cytology in the pistil. They may have been led to attribute cases of low seed set in the sweet potato to gametic extinction in consideration of evidence for the existence of partial homologies between chromosomes of the presumably different genomic constituents of the sweet potato (Ting and Kehr), 1953; Jones, 1965). However, both Ting and Kehr (1953) and Jones (1965) have discounted the influence of meiotic irregularity—and its associated pollen abnormality - as important components in the seed setting process in *I. batatas*. It will be recalled that the percentage of aborted pollen grains noted in the present study was negligibly small (Table 3). If swellings in the course of pollen tube growth identify sites of gametic loss due to unbalanced duplicate-deficient gamete formation in the hexaploid sweet potato, their regular occurrence in the diploid species *I. trichocarpa* and *I. gracilis* remains unexplained.

These considerations led the present authors to propose that matings which exhibit a wide range from low to high seed set in the species *I. batatas*, *I. trichocarpa* and *I. gracilis*, are associated with the occurrence of inflations in the progress of pollen tube growth. These inflations represent sites of gametic extinction associated with a genetic incompatibility mechanism which allows the expression of an intergrading series of compatibilities. Evidence for the existence of dominance relations among self-incompatibility alleles have already been presented by the present authors in the foregoing. We have also suggested that the evolution of an efficient incompatibility mechanism in the sweet potato may not be very far advanced. Th existence of incomplete dominance relations among incompatibility alleles resulting in failure to attain full fertility in a certain proportion of matings is, therefore, within the range of expectation for these phylogenetically retarded species.

The character of the distribution curve of fertility in *I. gracilis* and *I. trichocarpa* reported herein (Fig. 1) and their similarity to that reported in the sweet potato by other investigators would seem to support this hypothesis. Incomplete dominance of incompatibility alleles related to modification by the genetic background could result in a subjugation of their full penetrance and expressivity. This effect could explain the occurrence in these species of an intergrading series of fertilities from low to high levels. In the polyploid *I. batatas*, the super-imposition of competitive interaction in heterogenic gametes could lead to even finer graduations in compatibilites and fertilities.

The contribution of sterilities associated with unbalanced gametes cannot be completely discredited as a factor related to low seed set in the sweet potato. However, the cytological features of pollen tube growth in pistils may possibly point to a unique mode of origination of sterility systems in plants which could be highly correlated with the operation of the incompatibility system. Since pollen tube growth would seem to be a critically time-dependent process in these species, mechanical obstruction to penetration of fully compatible tubes by neighbouring pollen tubes with inflated tips, could conceivably retard their rapid delivery of gametes.

Intra- and inter-specific compatibilities in relation to ancestry in the sweet potato.

Intra-specific compatibilities found within *I. trichocarpa* and *I. gracilis*, in addition to other evidence concerning breeding behaviour in the sweet potato, document the authors' proposal that the sporophytic mode of self-incompatibility exists in the three species. Of particular significance in this context, was the recovery of phenotypes among progenies which recapitulated parental compatibility relationships in *I. trichocarpa* (Table 7).

The results of inter-specific hybridizations in the three *Ipomoea* species impinge on the issue of the mode of origin of the sweet potato. In the present study, apparently normal fruit development resulted from crosses between *I. gracilis* and *I. batatas* but seeds were non-viable. Chapman and Wedderburn (1966) achieved similarly successful fruit stimulation, but only in combinations in which *I. trichocarpa* was used as the female parent. These workers found that embryo development following such crosses was slow and ceased before cotyledon formation. Such results are typical of inter-specific crosses between species differing in chromosome number. The successful stimulation of embryo and fruit development in these hybridizations, suggest the existence of partial homologies between the genomes of each diploid species and sectors of the chromosome complement of *I. batatas*.

The experimental demonstration of the recovery of viable inter-specific hybrids between the diploid *I. gracilis* and *I. trichocarpa*, furnish more decisive information on the existence of homologies between the genomes of *I. gracilis* and *I. trichocarpa*. Chromosome relationships in the synthesised hybrid plants have not yet been examined, but the relatively high frequency of pollen abnormality observed indicates that substantial irregularities may exist at meiosis. The two hybrid plants proved to be completely sterile when selfed and when cross-pollinated. Germination of hybrid pollen on stigmas of some sweet potato cultivars indicated that some pollen grains were functional and suggest, in addition to the foregoing, the existence of a tripartite combination of genomic homologies among *I. trichocarpa*, *I. gracilis* and *I. batatas*.

The recovery of viable, inter-specific hybrids between the diploid species of *Ipomoea* and a consideration of cross-compatibility relationships among the three species, led the authors to propose a new hypothesis to explain the method of origination of the sweet potato: This species most likely arose by chromosome doubling of a sterile hybrid between two related diploid species one of which supplied an un-reduced gamete. At least one of these presumed progenitors must have been self-incompatible. But even if both species were self-incompatible, the proposition may still be valid, if it is conceded that the male species involved, was the parent which supplied the un-reduced gamete.

The implications of the findings presented in this study are wide ranging and perhaps, in some places, somewhat speculative. In this discussion, we have given a high degree of freedom to our thinking in the hope that our thoughts would stimulate further research into the many exciting avenues which await exploration within the genus *Ipomoea* L.

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IMPROVED TECHNIQUES IN BREEDING AND INHERITANCE OF SOME OF THE CHARACTERS IN THE SWEET POTATO, *IPOMOEA BATATAS* (L.)

— *by* —

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Since the inception of a breeding program in Louisiana by Miller (12, 13), new techniques have been developed and several genetic characters studied. The incompatibility system of varieties and seedlings in the United States and others is better understood (5, 6, 11, 14, 16, 17).

The sweet potato is a hexaploid with a basic number of 15 chromosomes (8, 9, 10) and like most vegetatively propagated crops it is very heterozygous. Several new varieties of great commercial significance (4) have been developed. One of the latest Louisiana varietal introductions, Centennial, is the leading variety grown in the United States. Several research workers have reported on the behaviour of some of the genetic characters in the sweet potato (1, 2, 3, 4, 7).

MATERIAL AND METHODS

A total of 28 sweet potato breeding parents was selected for these studies. The compatibility behaviour and phenotype of each parent was known. The varieties and seedlings were developed at Louisiana State University except Kandee from Kansas State Experiment Station; Whitestar; and seedlings P. I. 213321 and P. I. 227890 which are USDA introductions.

Controlled pollinations were made in field plot breeding nursery and in a greenhouse 20 x 120 feet where the sweet potato plants were trained on to a six foot netted wire trellis. The sparse flowering clones were cleft-grafted on to morning glory (Ipomoea spp.) root stock. Pollinations were begun in August and continued until October 25 of each year. Large soda straws were used after removing the corollas of the flower and subsequent emasculation to protect the pistils from contamination before and after pollinations. The controlled pollinations were made daily between 5:00 and 9:00 a.m. Pollen of each male parent was collected each morning from flowers protected by soda straws.

In January of each year the seeds were scarified in concentrated sulfuric acid for 25 minutes and thoroughly washed in tap water and dried. The seeds were then planted in greenhouse benches filled with a mixture of shredded sphagnum moss and silt loam soil. The seedlings were allowed to grow for approximately 4 months at which time they were pulled and transplanted to a field where the plants were spaced 5 feet apart on rows 4 feet wide. The seedlings were allowed to grow for another 4 months and then each seedling was classified as to plant characters and the roots harvested, bagged and labeled for further study.

RESULTS AND DISCUSSION

The objectives of the sweet potato breeding program are to continue a study of incompatibility systems, inheritance of genetic characters, and to develop new varieties with the following major characteristics: high yield, desirable skin and flesh color, good keeping quality, well shaped roots, good culinary quality, favourable sprout production, good adaptability, and resistance to several diseases, Fusarium wilt (*Fusarium oxysporum f. batatas*), soil rot (*Streptomyces ipomoea*), internal cork and root knot nematodes (*M. incognita*).

A total of 30 breeding parents were tested as to cross and self compatibility. There were 6 groups (5 incompatible and one self compatible) identified (5, 6).

The genetic characters studied are as follows:

Skin and Flesh Color. Control crosses between parents having different fleshy root skin color were made (Tables I and III). The skin colors were classified as white, cream, tan, copper, rose and purple. Seedling progenies of crosses between parents having fleshy roots of a cream and white skin color produced seedlings with roots of a white or cream skin (3). Segregates from progenies of cream x copper parents produced seedlings with fleshy roots that were predominantly copper as shown in Table III. Seedlings from crosses of copper x copper skinned parents were predominantly copper and tan. Copper x rose skinned parents produced seedlings that were also mostly of a copper skin color. Seedlings of crosses of rose x rose skin colored parents were predominantly copper and rose. In crosses of rose x purple skinned parents the resulting seedling progenies were mostly of a purple skin color. Colored skin color is incompletely dominant over white or cream skin color.

Flesh Color. Data from seedling progenies of crosses between parents containing varying amounts of carotenoid pigments were (Tables I and II) White fleshy root color was found to be incompletely dominant over the character for carotenoid pigments, which is mostly beta-carotene. A progeny of 195 seedlings between a cross of a white flesh and one having 18 mg. of carotenoids per 100 gm. fresh weight of root tissue produced 84.1 percent of the seedlings with little or no pigments. The progeny mean for carotenoids was 1.3 mg.

Crosses between parents having 6 and 12 mg. of carotenoids produced seedlings with a progeny mean of 8.3 mg. However, a cross between parents having 6 and 18 mg. of carotenoids had a progeny mean of 12.9 mg.

White flesh color is incompletely dominant over orange flesh color. The latter behave as a typical quantitative character. There are several genes controlling carotenoids (possibly 6) which have additive effects.

Dry Matter Content. Data from crosses between parents containing fleshy roots with varying amounts of dry matter showed that seedling progeny means were intermediate between the two parents. Transgressive segregation occurred in seedling progenies studied. This quantitative character shows in most cases additive genic effect. Transgressive inheritance is also suggested.

Fusarium Wilt Resistance. Fusarium wilt or stem rot is caused by the fungus, *Fusarium oxysporum f. batatas.* Since chemical fungicides and crop rotation offer no effective control of this soil-borne disease, breeding for resistance seems to be the best means of controlling this problem. The progenies of 29 crosses were evaluated as to Fusarium wilt resistance and statistical analysis of data shows large genetic differences for resistance transmitted by various parents.

Each seedling in each progeny was tested by cutting fresh ends of vine cuttings of each plant and dipping them in a spore suspension of Fusarium inoculum. Four treated cuttings planted in each of three 4-inch pots filled with clean sand constituted 3 replications. The variety Heartogold was treated and planted with each group of seedling progenies to use as a susceptible check; whereas, Goldrush treated the same as Heartogold was used as the resistant check. Crosses between parents represented: Resistant x highly resistant; moderately resistant x highly resistant; moderately resistant x moderately resistant; and moderately resistant x moderately susceptible parents.

Fusarium wilt index was computed for each seedling. Twelve plants from 3 replications of each seedling were placed in one of five categories as follows: 0 – stem of cutting showing no vascular discoloration; I – trace of vascular discoloration; II – moderate vascular discoloration; III – severe vascular discoloration; and IV – severe vascular discoloration. An index of each seedling was computed by using formula:

$$\text{Wilt index} = \frac{\text{Summation of category numbers x No. of plants in each category}}{\text{Number of plants tested x 4 (total no. of classes — 1)}} \times 100$$

The results in general indicated that crosses involving resistant x highly resistant and moderately resistant x moderately resistant parents gave the best results as a large percentage of seedlings of each progeny were resistent to Fusarium wilt. Crosses involving susceptible parents gave a very few resistant seedlings. Selfed progenies of Centennial and Kandee had a large number of resistant seedlings in each progeny. The selfed progeny of L130 had only a few moderately resistant seedlings. The parents Julian, Whitestar, and L21 carried several genes for resistance. Some parents transmitted considerable resistance and Julian was outstanding. This quantitative character is controlled by possibly six genes that are additive. Transgressive inheritance is indicated in crosses between some parents.

Quality Studies The major characters affecting the culinary qualities of sweet potatoes are: flesh color, flavor, texture, fiber content, sweetness, moistness, and general acceptability of sweet potato roots baked or processed (Tables I and IV). A baking index was obtained by calculating a mean score rating of all seven factors. Scoring was based on a range of 0 to 10; 10 representing the maximum favorable expression for each above character with the exception of fiber in which 10 represented an absence of fiber. Since white flesh color is incompletely dominant, the seedlings from crosses using a white flesh parent produced seedlings that rated poorly in color after processing or baking. In crosses of parents that rated medium to good in baking quality, the majority of the seedlings rated fair to good in quality.

Seedling progeny means from crosses of parents of acceptable culinary quality were intermediate between parents or acceptable.

Breeding Technique. The following technique of this highly heterozygous crop has been successfully used at Louisiana State University. Breeding parents are selected on the basis of field performance and genotype as indicated by expression of phenotypic characters. The parents selected are of as many different incompatibility groups as possible and have two or more of the following characters: high yielding ability; well shaped roots; copper or rose skin color; all parents having orange flesh with 3 or more mg/100 gm. of carotenoids per 100 gm. fleshy roots; moderate to good plant production; good culinary quality; profuse flowering; and disease and/or insect resistance. These parents are placed in an isolated nursery, trained onto a wire trellis and allowed to pollinate at random by honey and bumble bees. The seeds are identified as to maternal parent and scarified in sulfuric acid for 25 minutes, washed in water and dried. The seeds are planted in a greenhouse bench in a good medium, spacing seed 2 inches apart. They are allowed to grow for four months. By that time each seedling has produced a fleshy root approximately one inch in diameter. The seedlings are pulled, and using high selection pressure, best seedlings are saved. This includes seedlings having colored skin, preferably tan, copper or rose, orange flesh, and well shaped roots. The white flesh seedlings are discarded as well as seedlings with irregularly shaped roots. Using this basis for selection, approximately 10 percent of the seedlings are saved and transplanted to the field. After 4 months of growth each seedling is harvested and approximately 15 percent of these are saved for subsequent testing. The roots of each seedling are bagged and labeled. The numbering system in each year includes the last number of the year and adding a selection number of 1 to infinity, e.g., in 1966 the first seedling would be 6-1 and the second 6-2, etc. Every 10 years a recurrence of this number would occur; however, generally all seedlings have been discarded or named as varieties.

For genetic studies, controlled crosses are made as indicated earlier in this paper.

The above method of varietal improvement permits a genotype that possesses a balanced genic system that allows maximum expression of desirable quantitative characters and at the same time allowing a vigorous plant that yields well. This method is called the Polycross system.

SUMMARY

Several major horticultural characters were studied as follows: skin and flesh color, culinary quality, dry matter content and resistance to Fusarium wilt. These behave as quantitative genetic characters. White flesh color is incompletely dominant. Transgressive inheritance is indicated in some crosses.

Crosses between parents having an acceptable culinary quality produced progenies that had most of the seedlings that were acceptable and the progeny means were intermediate between the two parents.

The breeding parents are classified as to incompatibility groups and a search is being made for more self fertile or self compatible parents.

A breeding technique was described.

Table I. Characters of Sweet Potato Breeding Parents

Parent	Skin Color	% Dry Matter	Carotenoids mg/100 gm	Baking Quality
Julian	Copper	28.4	18.5	Good
L8-67	Rose	27.2	17.5	Good
L1-80	Copper	29.4	18.0	Good
Centennial	Copper-Tan	29.0	16.1	Good
L0-240	Purple	27.0	16.5	Medium
L3-7	Copper	36.5	11.7	Medium
L3-64	Rose	30.8	11.0	Good
L3-80	Rose	30.8	10.4	Medium
L2-61	Purple	30.6	8.6	Poor
L131	Cream	29.6	7.0	Medium
Georgia Red	Rose	29.3	5.2	Good
Porto Rico	Copper	29.4	5.2	Good
Kandee	Light Copper	28.7	4.6	Poor
L130	Rose	31.3	4.2	Medium
L21	Light Copper	32.6	1.2	Poor
Whitestar	Cream	34.3	0.4	Poor
Pelican Processor	White	38.4	0.0	Poor
P.I. 213321	White	29.5	0.0	Poor
P.I. 227890	Purple	36.6	0.0	Poor

Table II. Frequency Distribution of Sweet Potato Seedlings into Different Total Carotenoid Pigment Classes.

Parental Combination	Total No. Seedlings	Number of Seedlings into Each Class 0	0.1-3	3-6	6-9	9-12	12-15	15-18	18-21	21+	Progeny Mean
Centennial (X)	164	21	19	5	9	14	11	24	37	24	13.0
Kandee (X)	67	23	14	9	3	4	4	6	4	0	5.1
Julian x L21	229	15	8	21	16	19	17	24	70	43	15.2
L3-7 x L1-80	116	11	4	5	8	6	9	17	28	29	15.6
L2-61 x Ga Red	100	16	11	8	8	6	10	24	16	1	10.4
L2-61 x L131	339	26	32	7	14	26	68	109	55	2	12.7
L8-67 x L131	128	8	2	1	3	4	10	30	60	20	16.4
P.I. 213321 x L1-80	258	160	57	24	7	5	4	1	0	0	1.5
P.I. 213321 x L21	239	221	16	0	1	1	0	0	0	0	0.1
P.I. 227890 x L21	179	170	6	2	1	0	0	0	0	0	0.1
Centennial x L1-80	98	7	3	6	4	8	9	13	19	29	15.7

Table III. Frequency Distribution of Sweet Potato Seedlings into Different Skin Colour Classes.

Parental Cross	No. of Seedlings	Percentage of Seedlings into each Skin Color					
		White	Cream	Tan	Copper	Rose	Purple
Copper (X)	57	0.0	5.3	22.8	43.9	7.0	21.0
White x Copper	357	13.4	17.4	27.5	22.7	11.2	7.8
Cream x Copper	166	1.2	7.2	33.1	37.3	12.7	8.5
Cream x Rose	27	0.0	0.0	33.3	29.6	11.2	25.9
Cream x Purple	32	0.0	0.0	15.6	21.9	21.9	40.6
Copper x Copper	373	0.3	7.8	25.2	45.3	13.1	8.3
Copper x Rose	443	0.2	3.6	20.3	51.5	16.0	8.4
Copper x Purple	18	0.0	0.0	16.7	5.6	44.4	33.3
Rose x Rose	58	0.0	5.1	17.2	32.8	25.9	19.0
Rose x Purple	21	0.0	0.0	0.0	4.8	9.5	85.7

Table IV. Inheritance of Baking Quality in Sweet Potatoes

Parental Combination	Cross	Characters* of Fleshy Roots: Color	Flavor	Texture	Fiber	Sweetness	Moistness	General Acceptability	Progeny Mean Baking Index
P. I. 213321 x L21	Poor x Poor	0.4	2.2	3.9	6.4	2.7	3.0	0.8	2.8
P. I. 213321 x L1-80	Poor x Good	1.7	3.0	4.6	6.2	3.3	3.7	2.0	3.5
Centennial x L1-80	Good x Good	6.3	5.6	6.1	5.7	5.6	6.2	5.5	5.9
Centennial x L3-80	Good x Med.	4.7	5.0	5.4	5.9	4.9	5.3	4.3	5.1
L3-7 x L3-80	Med. x Med.	5.0	5.2	5.4	5.9	5.2	5.2	4.7	5.2
L3-7 x L1-80	Med. x Good	5.8	6.0	6.3	6.1	6.0	6.3	5.8	6.1
L130 x L1-80	Med. x Good	4.8	5.4	5.7	5.2	5.5	6.0	4.7	5.3
L130 x L8-67	Med. x Good	4.9	5.0	5.8	5.6	5.2	6.2	4.5	5.3
L1-80 x L3-80	Good x Med.	5.6	5.4	5.9	5.6	5.4	5.6	5.0	5.5
L1-80 x L3-64	Good x Good	5.7	5.2	5.8	5.8	5.3	6.1	5.1	5.6

*Scored on the basis of 0–10, 10 representing the maximum favourable expression of each factor.

Table V. Inheritance of Fusarium Wilt Resistance in Sweet potatoes

Parental Cross	Wilt Index of Parents	No. of Seedlings	Progeny Mean Wilt Index	Percentage* R.	M. S.	S.
L1-80 x L3-80	50 x 55	60	56.5	71.7	28.3	—
P. I. 213321 x L1-80	49 x 50	236	52.0	49.2	36.0	14.8
L8-3 x L1-80	37 x 50	42	58.5	26.2	59.5	14.3
Centennial x L1-80	60 x 50	118	60.4	46.6	39.8	—
L3-7 x L1-80	53 x 50	165	49.6	85.5	10.9	3.6
L130 x L1-80	60 x 50	67	56.2	70.1	25.4	4.5
L131 x L1-80	67 x 50	55	52.1	78.2	21.8	—
L3-93 x L1-80	83 x 50	99	67.8	22.2	66.7	11.1
L130 x L1-80	60 x 50	67	56.2	70.1	25.4	4.5
L131 x L1-80	67 x 50	55	52.1	78.2	21.8	—
L2-61 x L131	34 x 67	361	70.5	22.2	44.5	33.3
L8-67 x L131	60 x 67	106	67.7	25.5	59.4	15.1
Centennial x L131	60 x 67	43	63.7	32.6	46.5	20.9
L3-93 x L131	83 x 67	86	69.3	24.4	53.5	22.1
Tanhoma x L131	71 x 67	94	77.6	—	44.7	55.3
Whitestar x L21	30 x 20	41	47.9	80.5	19.5	—
P. I. 213321 x L21	49 x 20	215	65.0	37.6	42.5	19.6
P. I. 227890 x L21	45 x 20	180	52.1	76.7	19.4	3.9
Julian x L21	37 x 20	226	30.3	100.0		
Centennial x L21	60 x 20	84	61.5	45.3	45.3	9.4
Centennial x Kandee	60 x 80	59	66.4	27.1	45.8	27.1
Centennial x L1-80	60 x 50	118	60.4	46.6	39.8	13.6
Centennial x L21	60 x 20	84	61.5	45.3	45.3	9.4
Centennial x L3-80	60 x 55	213	69.7	17.8	46.0	36.2
Centennial (X)	60 x 60	142	54.7	69.6	15.5	4.9

*R — Resistant; M.S. — Moderately Susceptible; S — Susceptible.

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DISCUSSION I

Prof. Harland :

The meeting is now open for discussion on these three papers. Now if anybody wishes to take part will they give their names so that we can have this recorded.

Dr. Magoon :

Dr. Martin has indicated both the polyploid nature as well as the existence of homology amongst the genomes in sweet potato based only on the evidence of the occurrence of secondary pairing of chromosomes at meiosis. Likewise, secondary association of chromosomes at meiotic metaphase has also been used as a tool by some workers for postulating the genomic constitution and the relationship amongst these genomes in sweet potato, in spite of the fact that the exact significance of this phenomenon has been a matter of considerable controversy. As you know, secondary association is the term applied by Darlington (1937) to the close juxtaposition of bivalents, or higher association in metaphase I, or of split chromosomes in metaphase II; the occurrence of secondary association has been believed to be the result of a residual affinity between chromosomes which are phylogenetically or ancestrally related. Such secondary pairing is not accompanied by the formation of chiasmata. This phenomenon, first observed by Kuwada (1910) in *Oryza sativa*, has been extensively discussed by Lawrence (1931). According to the last author, secondary association may occur from pro-metaphase to second anaphase, but cannot be detected at the diakinetic stage because of inter-bivalent repulsion, unlike the associations resulting from primary pairing which are held together even at diakinesis. This phenomenon is more easily recognizable in organisms with short chromosomes than in those with long chromosomes.

He pointed out that the quality of fixation is of great importance in connection with studies on secondary association and suggested that three criteria, viz. (1) the association must be shown to be constant in the best fixation, (2) the average number of chromosomes per association and the frequency for each kind of association should be characteristic for a given species but may vary from species to species and (3) at first metaphase associated bivalents should be shown to be of similar size and configuration, should be satisfied before such secondary grouping in any one case is accepted as a real phenomenon and not an artefact. Several workers, subsequently accepted the views of Lawrence (1931) regarding the nature of secondary pairing and utilized the data of secondary groupings as an evidence in deciding the level of ploidy of any taxon or group of taxa. As I have already indicated, differences of opinion, however, exist regarding the real significance of secondary pairing of chromosomes. Factors, other than ancestral homology, have been implicated as being responsible for this phenomenon by a number of workers based on their work in different crop plants. Their observations on secondary associations have shown marked heterogeneity, even where the same species were analyzed. The lack of suitable techniques and the small size of the chromosomes, as well as, the lack of suitable morphological markers on the chromosomes, prevented very accurate analysis of bodies which take part in such associations. Further, it is liable to be greatly modified by segmental interchange, duplication of chromosome segments and other phenomena, not at all related to polyploidy. It is, therefore, not an entirely reliable index of the exact basic haploid number possessed by the original ancestors of a group. It would, therefore, appear, in my opinion that a very cautious approach is necessary in using this evidence alone to derive genomic constitution and their relationships, polyploid origin and basic chromosome number of the genus.

Dr. Martin :

I agree with your comments on the cautious use of secondary association. It is indeed a very weak form of evidence. However, in the sweet potato at the present time we do not have any good evidence of the kind of crosses to allow us to test genomic relationships. Dr. Alfred Jones of Tifton, Georgia, has been working on this and is trying to develop plants that will cross with the sweet potato by hybridizing and developing new ployploids, but so far he has not had any luck in developing such types of analysis. It is something that we need but, something which, because of the strong barriers between species, we have not succeeded in doing so. With respect to my own comments, I was trying to develop this as a theory and I would not put too much emphasis myself on secondary pairing.

Dr. Yen :

I would just like to comment on the cytological aspect that has been arraigned mainly because in the work we did with the Pacific sweet potato collection, we also had to do cytological work. The first specimen we worked on was a New Guinea one, and thought then we could use this as a quantitative character, similar to a morphological character to try to characterise our collection from all over the Pacific. However, it was not very long before we struck from Thailand, Fiji, and Peru what could not be secondary association but since they were so close, other workers in other parts would call these things multivalents. Now we thought that perhaps we were taking too much of a flight of fancy about this so we subjected our material to Dr. John Hare, a cytologist. His answer was immediately that we had multivalency. The second thing was to try to get some of the correlations that Dr. Martin and others had tried to get from this kind of chromosome behaviour. I can only report here that we had all sorts of abnormalities occurring in our cytological material, such as counting of nuclei and so forth, but we could not correlate it with sterility at all, as Dr. Martin has pointed out to us.

Mr. Williams :

I would like to say that, with relevance to the comments by Dr. Yen and Dr Martin, the theory for the origination of sweet potato, which we have proposed in our paper, permits the possibility that the sweet potato could be an auto-hexaploid. If the progenitor species were self - incompatible and self - pollination with an unreduced male gamete occurred, then, because of the possible opportunity for the action of competitive interaction between heterogenic alleles in one pollen grain, it is conceivable that a triploid offspring could be formed. This, followed by doubling, could result in the generation of an auto-hexaploid.

Dr. Magoon :

What evidence do you have in proposing a theory that sweet potato could be an auto-hexaploid ?

Mr. Williams :

I did not say that I was proposing a theory that the sweet potato was not a hexaploid. I said that the theory of a possible method of origin of this species permits this possibility — the theory of the supply of unreduced gametes. But even if it did in fact originate in such a manner, there could have been, in the revolutionary history of this plant, a lot of opportunity for segmental differentiation of some of the genomes and selection for meiotic stability so that you could get a high frequency of bivalent pairing in the present-day species.

Dr. Cope :

I would like to ask Dr. Martin whether he has found evidence of homozygosity for incompatibility alleles in Ipomoea species. He mentions the segregation of parental types in that one plant as evidence for sporophytic control. Has he also found homozygosity ?

Dr. Martin :

Well I did not mention sporophytic control of self-incompatibility and, in fact, I am a little reluctant to say very much about the incompatibility system until we complete our own analysis of it, although I do have my own opinions on it. But now, as far as the possibility of homozygous alleles in the sweet potato, I think the possibility is very high because we run into these exceptional cases of crossing in which there is a unilateral incompatibility between two different plants. In other words, the cross can take place in one direction but not in the other, and in such a case we might expect that one of the alleles was in a homozygous state. This unilateral incompatibility does not seem to be the regular case. It has only been recorded on very much of a scale by one investigator, although other investigators have found unusual plants that did not fit into their schemes. Finally, I would like to say that with the Ipomoea species that I have been working with, where the incompatibility is not confused with sterility, all of the crosses are mutually compatible or mutually incompatible. There is none of this unilateral incompatibility, which makes it look as if there is a sort of a breakdown in the sweet potato, a partial incompatibility permitting the fixation of S-genes once in a while.

Mr. Gooding :

I would like to ask Dr. Hernandez one or two questions. As one who is interested in food processing as well as in agriculture, I am rather interested in those correlations between baking quality and various other characteristics, some of which seem extraordinarily unlikely, e.g. baking quality and colour. It seems strange, that there should be such a high positive correlation. And baking quality and moistness. I am not quite sure what you meant by moistness — whether it is directly related to water content or to solid content or what. Could you expand a little bit on these please ?

Dr. Hernandez :

I shall be glad. Let me say, in baking quality, we do not consider the baking index to be composed of a mean of all the characters indicated viz. sweetness, moistness and so forth. Now, I am referring to a moist fleshed sweet potato as opposed to a dry fleshed type. Now there appears to be somewhat of a linkage between many of these characters and colour which I am talking about, so that a high quality sweet potato to us, is a sweet potato that will bake sweet, soft, moist and of course, has a high carotenoid pigment content. And it seems that we have had difficulty in obtaining a high dry matter with a high carotenoid pigment content in seedlings. In our selection programme throughout the years we aimed at reaching a point of homozygosity with most of these characters. So far, we have recovered many seedlings which combine most of these desirable horticultural characters.

Mr. Gooding :

Thank you, I was making a mistake in assuming that baking quality has been a rather isolated factor particularly related to the texture of the finished product, rather than taking the other things into consideration as well.

Prof. Skelding :

I would like to ask Dr. Martin whether in his list of causes of incompatibility he has any evidence of incompatibility between endosperm and embryo coming into the picture at all.

Dr. Martin :

Really, I do not think that I have analysed that factor sufficiently to eliminate the possibility that there is some endosperm-embryo incompatibility in the non-viable seeds of the sweet potato. Of course, there is very little endosperm in these and it is my opinion, at least at this time, that failure of germination is not a matter of incompatibility but due to the fact that the endosperm is not fully formed or not sufficiently large to support the embryo.

Dr. Milthorpe :

I would just like to ask one small question. If one uses the trick which the breeders of Irish potato use of removing the tubers during the early stage of development, could this influence the proportion of seed which develop ?

Dr. Hernandez :

Well in our case we have not had any difficulty in obtaining progress. Tuber removal as far as we are concerned, does not have any direct bearing on seed maturation — as long as the plant blooms of course. I think the previous speaker had not mentioned the effect of environment on seed set which plays a very important role i.e. temperature, humidity and so forth. We observed however, that tuber removal increased flowering intensity and seed set.

Dr. Martin :

I agree with M. Hernandez that environment does have a strong influence on the amount of seed set in the sweet potato. Yet, when one compares the maximum seed set that can be had in a cross with the minimum set under the most unfavourable circumstances, the amount of seed set is still rather small in comparison with the reproductive potential of the species. This is why I personally have not emphasised these environmental factors. Furthermore, a very large range of environmental factors have been studied by some investigators and in all cases, although there are some changes in percentage seed set, these changes have been small compared to the total sterility picture.

Prof. Harland :

I think that since there are no more contributions from the floor I would like to philosophize for a moment. First of all, I think we might accept provisionally Mr Williams' theory that the sweet potato is the result of the crossing of two diploid species, probably one contributing an unreduced gamete followed by doubling of the chromosomes to produce a hexaploid. Now in this case, both of the contributing species, I think, must have contributed a self-incompatibility mechanism, and if one of the species was contributing an unreduced gamete, you get two sets of incompatibility mechanisms in one of the components and a single one in the other. Actually, it seems to be reasonable to suppose that you can get inter-incompatible and compatible groups and it therefore seems likely that one of the self-incompatibility mechanisms from one of the species has made a take-over bid, taking over the mechanism. Now this would mean that mutation could occur in the other self-incompatibility mechanisms leading to their almost but not quite total reduction. Now the whole situation is of course complicated by sterility. I think if we philosophize again, the impairment of the reproductive mechanisms is of course common to all or most vegetatively reproduced plants. Once you go over mainly to vegetative reproduction — as in the case of the sweet potato — the normal reproductive mechanism is no longer required to operate at 100% efficiency and, as in the case of organisms which are confined to caves, over geological times, you get in these organisms a complete breakdown of the eye mechanisms so that the organism becomes blind. In this case, when the reproductive mechanism is not essential for the perpetuation of the species, you get genetical breakdown, mutation in the reproductive complex which is unopposed by selection and I venture to think that the sweet potato has gone pretty far along that path. Now this process, whereby unwanted or unnecessary genic complexes mutate unopposed by selection, is called genetical erosion and you can find numerous instances in the plant kingdom where this process has taken place.

THE ECONOMIC ASPECTS OF THE PACIFIC SWEET POTATO COLLECTION

— *by* —

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The collection of sweet potato varieties from the Pacific Islands was begun in 1957 with its objective being mainly ethnological in interest (Yen, 1963a). The plant, *Ipomoea batatas* (L.) Lam., first identified specifically by the botanists with James Cook has offered an enigma in the general topic of the peopling of the Pacific, for the debated American origin assigned to the plant forced the recognition of the possibility of prehistoric contacts with the New World (Dixon, 1932). The scope of collection was extended to America and Asia in the light of the unsettled issue of origin, since the evidence of Vavilov (1931: 1949/50) for South American or Mexican provenance has not been defined. The live collection, grown in New Zealand as it was gradually accumulated from successive field trips, demonstrated the comparative variability of varietal populations from the broad geographical areas, and indicated that the ultimate source of the Polynesian, Melanesian and Asian material was America. A report on the incomplete material (Yen, 1963b) showed that the area of provenance for the whole Pacific material could have been identified as South America.

The full collection of 580 varieties was grown for the final comparison in the 1963/1964 season. Cytological investigation has produced little that could differentiate the populations (Wheeler and Yen, *manuscript*), but the addition of varieties from areas previously unrepresented has allowed some further interpretations of the manner of distribution of the plant. While this is not the subject under discussion, the extension of the measurements of variation in its pursuance since 1963 has encompassed some plant characters which are considered to be of economic value. These, then, comprise the focus of this paper. Further, the information gained in the course of fieldwork on the adaptation of the plant into indigenous environments is considered in conjunction with the economic characters in the plant's variability.

The possible contributions of this collection in plant improvement are seen as two-fold:

1. The variation displayed within the species of the characters measured shows that further assessments in depth for as many economic characters as possible may reveal genetic material for the improvement of the plant in modern horticulture.

2. Some selection directions for native cultivation may be somewhat divergent: the definitions of the problems or limitations to production and the selection of parental genetic material of the modern approach to plant improvement may be combined with the selective processes of the cultivators in the multifarious environments under which the plants are grown.

SOME ECONOMIC CHARACTERS FOR MODERN HORTICULTURE

The variations that have been recorded in the sweet potato may be described as extremely wide in character. While the data on the individual morphological traits may suggest that some grouping of these may occur to give at least some sub-specific taxonomic classification, the attempts to achieve this in this collection have resulted in the concept that the species is a highly variable one, with free gene interchange, compatible with the hypothesis of its allopolyploid parentage (Ting and Kehr, 1953), with interference to evolution by the human agency of vegetative propagation (Yen, 1961a).

Since the fuller data is to be published elsewhere, this discussion is restricted to the description of information relevent to the possible implications to plant improvement.

The general indications of the wider range of variability of the American material over the remainder of the populations held good in the expanded material, and over a greater number of plant characters than were included in the preliminary report (Yen, 1963b). At one end of the ranges in four characters, however, the American variability was exceeded with: near glabrous reproductive parts of the flower in some Thai, Philippine and New Guinea varieties; the greater degree of dissection of leaves in some New Guinea varieties; the presence of a mauve rather than white stigma in some New Guinea and Philippine varieties and the lowest specific gravity of edible roots recorded in the collection in one Marquesas Island variety. In 37 other plant characters, the American varieties covered the widest range exhibited in the collection. Thus it is the American portion of the collection which must be expected to yield the highest potential as a gene source for modern plant breeding. Some of the characters assessed in this work of such value may now be described.

The problem of sweet potato production on which many breeders are concentrating are those caused by disease pathogens. As a source of resistance to black rot caused by *Ceratocystis fimbriata* Ell. & Halst, and scurf by *Monilochaetes infuscans* Ell. & Halst., the collection seems to hold considerable promise, for in tests of root inoculation with the two organisms, some varieties exhibit resistance, or at least high tolerance to the diseases (Nielsen and Yen, 1966). The six most resistant varieties to black rot are from Peru (5) and Ecuador, and to scurf from Peru, Ecuador (1), Colombia (1) and the Ryukyu Islands (1). In connection with the previous comment on the free segregating nature of the species, it should be noted that in no case, has one variety scored highly for resistance to both organisms.

The importance of these observations do not lie in the identifications of the resistances, for varietal differences of reaction to black rot have been recorded by Chen (1953) and Martin (1954), and to scurf by Poole (1932) and Kantes and Cox (1958). The variability over a wider range of material than is usually tested, however, indicates that there may be more effective resistances than are presently known: that the seemingly quantitative inheritance of the resistance reactions may allow of a building up of resistance by selection in breeding populations from hybridisations of varieties; that there may be further resistances to other economic diseases within the collection. Using material from the collection, Martin (1966) has investigated the reaction of varieties to soil rot (*Streptomyces ipomoea* Person & Martin). His so-far unpublished results from tests devised by Carlson and Struble (1960), of the correlation of low numbers of layers of non-nucleated periderm root tissue and resistance to this disease indicate the strong possibility of resistance which could be higher than some common American commercial varieties derived from varieties from South America, the Marquesas Islands and New Guinea.

The further distribution of material from the collection to sweet potato breeders working with plant pathologists may well produce more useful resistance characteristics. While this may be considered as the greatest potential for the collection as a source of genetic factors, there are some other interesting plant characters which may be of use in breeding programmes.

One is growth habit of the plant. There are two varieties, one Mexican and one Peruvian which display shorter vine lengths (the product of short internodes and low number of nodes) which extend to only a mean of 15 inches at maturity under New Zealand conditions. These vary from one another however in that the Mexican variety has prostrate stems while the Peruvian is upright. The utility of such characters may be more apparent with the modern agronomic trends toward the minimisation of herbage growth to facilitate bulk harvest methods, and closer planting spacings to produce uniform and somewhat smaller roots.

A further example is one directly concerned with production, and while applicable only to New Zealand conditions, may point to possibilities in other temperate areas. It has been shown (Yen, 1963b) that there is segregation in the species in the ability of individual clones to set swollen storage roots in New Zealand. Of those which do, there is a wide variation exhibited in measurements of production based on per plant figures of number of edible roots, or weight. In the most recent comparative growing for example, the standard New Zealand variety, *Owairaka Red* produced mean figures of 5.2 roots per plant with a weight of 3.7 lbs. These were exceeded, as in previous comparisons, by a number of imported varieties, but despite the further additions to the material, the performances outstanding in these indicants of yield were repeated by two Peruvian varieties, one bearing nearly 18 roots for only 3 lbs weight per plant, but of a size useful in canning, and the other with only four roots but weighing nearly 7 lbs per plant. It is unfortunate, that in other characters, these varieties are unsuited for direct introduction into New Zealand commercial growing, but they are being investigated further in their breeding potential.

The records of specific gravity of roots grown in the experimental plots have shown that the figures of between .95 and 1.09 for the collection exhibit a range of variation in access of that of the *Solanum* potato. The latter, with a range of 1.06 – 1.12 (Schippers, 1963), must be considered a better source of starch, but in tropical climates, the comparative gross production per acre would favour the sweet potato. That there is scope for selection in the species, particularly where solids contents are important as in some forms of processing, may be taken as unquestionable as shown by the variation in this collection. In terms of seeking products from tropical areas for modern use, however, the competitive nature of other starchy root crops, e.g. manioc, has to be taken into account.

ECONOMIC CHARACTERS IN INDIGENOUS CULTIVATIONS

The adaptability of the plant in Pacific native agricultural contexts takes on a rather different identity, for both the environments in which the sweet potato is grown and its cultivation methods are more contrastive with modern horticulture than, for example, the grain cultures of the Middle East and Western Europe. It is well to pause in consideration of these differences, for they have direct bearing on the choice of objectives in plant improvement for the area.

The adaptability of the plant over a wide range of environmental conditions is demonstrated in Oceania, for it is found within the agricultural contexts of low-lying coral atolls and the high volcanic islands (Barrau, 1958 ; 1961). The sweet potato has been collected in gardens on the sandy and coral derived soils close to island shores, from drained swamp areas and from hill cultivations up to 5000 feet in elevation. Generally, the plant here is associated in agricultural systems with perennial tree crops like banana, sago, coconut, breadfruit, and other major starch sources such as taro, yam, manioc, often occupying a secondary, supplementary role. At levels of 5000 feet and over on the continental islands the plant assumes a major role. In Luzon, it is the major component in the cropping pattern of the shifting cultivation element of the steep, higher slopes which accompanies the permanent field rice terrace cultivations. In New Guinea, over a million mountain people (the estimate for the Australian central highlands is around one million, Watson, 1964) are largely dependent on the sweet potato for their subsistence. It may be said that among contemporary indigenous societies, that the sweet potato has been adapted in agricultural systems which incorporate the slash-and-burn or milpa methods in slope cultivations. The spatial succession in terms of altitude of crop plant importance has been noted by several authors, e.g., Barrau, 1958; Brookfield, 1964, for New Guinea, and the place of the sweet potato at the maximum levels of agriculture at approximately 8000 feet pointed out. The inferences for the adaptation of the plant lie in two directions — the ability to grow on steep topographies, and some tolerance to the cooler conditions. The pre-historical distribution of the plant as a major agricultural plant in peripheral Polynesia may reflect somewhat this adaptation; for in Hawaii the plant occupied the principal role in *kula* (dryland mountain) cultivation (Handy, 1940), the Easter Islanders relied on the plant since many of the other Polynesian staple plants like coconut, breadfruit grew poorly; in New Zealand, the sweet potato was adapted to the more temperate environment after the invention of the Maoris of underground storage techniques which allowed the plant to be grown as a virtual annual plant (Yen, 1961b).

The adaptation of the plant to the relatively atypical tropical conditions may be seen as the interaction between modification of the environment by cultivators — agricultural methods — and the inherent genetic ability of the plant in its variability to withstand the natural environment. It is the latter aspect on which attention is focussed.

The growth habit of the sweet potato plant, referred to earlier, has been classed into several forms, and those which achieve the fastest growth in terms of ground cover are seen to be the most suited to mountain landscapes. Of all the plants grown as starch staples in the tropics, the sweet potato must be regarded as the best for its soil-containing possibilities. The extremes in the range of variation of growth habit, however, the bush types with agronomic possibilities in modern horticulture, and the very long vined forms with long internodes (over 10 cms. in some Peruvian and Columbian types), with poor branching development, do not provide effective plant density. The intermediate types of rapid growth and profuse branching patterns appear as the most effective.

The testing of 293 varieties from the collection for reaction to cold in New Zealand proved that the species can be segregated into classes of degrees of tolerance. While no varieties withstood sustained low temperatures at or near frost level 32 degrees F.), many, even those derived from lowland tropic regions, exhibited surprising tolerance. It is therefore suggested that in high tropic areas where unpredictable cold conditions can prove disastrous to sweet potato production, and therefore to the food supply levels, e.g., in New Guinea (Meggit, 1958; *South Pacific Post*, 1961), the purposeful selection of cold tolerant genes may be an important stabilising production factor in such economies. Some trends of exploitation of sub-alpine areas about 8000 feet, as described by Bowers (1965), however, may be limited by the demand on the species to withstand further cold conditions, and the substitution of other crops e.g., the *Solanum* potato as suggested by Keleny (1960) may have to be extended if agricultural expansion continues. Comparable heights have not yet been reached in Philippines indigenous agriculture, but should demographic changes owing to improvements in human hygiene and health measures result in upward trends, adjustments in agriculture may occur in the intensification of efforts on the swidden portion rather than the permanent rice field. The limitations to the latter may be seen not only in the additional expenditure of labour to create or elaborate agricultural capital, but also in terms of the adaptation of rice to higher altitudes, the amounts of land suited to terracing, and especially, the available supplies of water for irrigation.

A further measure of adaptability is in the occurrence of plant disease disorders caused by pathogens. The ranges of diseases known in the sweet potato of American horticulture have not been identified in native agricultural contexts, but during field work, the incidences of diseases have often been observed on a large scale. In lower altitudinal zones, e.g. below 5000 feet in New Guinea and in hill cultivations not far from the sea, but under 1000 feet in elevation, the leaf disease caused by *Elsinoe* sp. appears to be of considerably more importance as a limiting factor of production than in other areas. In the higher elevations in New Guinea, the disease was not observed. The identification of diseases is a pre-requisite to improvement for such areas, and the possibility of physiological races of organisms over the wide ecology of the Pacific may pose further problematic situations that are not uncommonly encountered by plant breeders.

In the side issue of human adaptation in an area like continental New Guinea, the effect of diseases in agricultural plants in the warm humid zones of coasts and middle altitudes may have to be considered along with other ecological considerations, the prevalence of human diseases and the social pressures on land resources in the story of the expansion of populations into the upland areas. The dependence of these peoples on the sweet potato invests it with the responsibility of not only the main contributor to caloric intake, but the nutritional quality aspect of the diet. The lack of protein is perhaps its most serious defect, especially where alternative sources are poor, e.g. in New Guinea (Bailey, 1963). Oomen *et al* 1961) have pointed out possibilities of selection in this character, for the variability that was encountered suggests similarity to the characters explored in the Pacific collection.

The dual-purpose utilisation of the sweet potato in the Pacific has considerably more emphasis in native agricultures, for the plant provides both leaf and starchy root resources in the diets of humans and animals, and particularly in pig-raising. The social consequences of the sweet potato in terms of its effect on human population (Watson, 1965) in New Guinea may also apply to swine-herd populations, for the role of pigs in economic and ceremonial life is extensive (Vayda *et al*, 1961). The feeding of sweet potato roots may be generally assigned to surplus and discarded production, but two methods of feeding herbage are employed. One is by the cutting of stems and leaves expressly for direct feeding to pigs — sometimes in Asia, they are chopped and boiled with household scraps first; and by "controlled grazing" of fields, generally after the main root harvests. The involuntary breaking-in to cultivations by domestic and the sometimes hunted feral pigs constitutes an indirect, but by no means, infrequent contribution to the food supply. Fortunately, the improvement of this aspect of utilisation by selection is parallel to the requirements of plant type for slope cultivation, for it is the "intermediate" fast-growing types which have the ability to recover after cutting, and perhaps, after controlled grazing. From South China, there is information on utilisation that indicates that selection is practiced towards the glabrous stem and leaf forms on the score of their suitability for both human and animal consumption.

The foregoing may convey that in Pacific indigenous agriculture, there are no plant selective procedures. This impression should be corrected. In a previous paper (Yen, 1967), some of the ecological and social phenomena which render these procedures less apparent have been outlined. The directions of selection appear to be towards some of the characters that have been treated, but it is considered that the assistance of modern breeding methods may accelerate such effects by the concentrating genetic diversity towards the desirable ends of the ranges of variation.

THE POSSIBILITIES OF UTILISATION OF THE COLLECTION

The modern trend in plant breeding is toward the elimination or minimising limiting factors to production, the fitting of the plant to advanced techniques of cultivation and harvest and the improvement of quality for specific ends, e.g. processing, while at least maintaining production level. The exploitation of the Pacific collection, including the important South American array, lies in the search for useful gene contributions to these ends. Apart from indicating this potential, there is little point in further elaboration, for the approach merely represents what has become a classical approach to the improvement of crop plants — the exploration of materials collected from indigenous cultivation contexts. The problems of breeding procedures in the sweet potato, the improvements in techniques and the refinements in the methods of assessments of the various required qualities are to be discussed in this symposium.

If the improvement of sweet potato stocks in indigenous cultivations were to follow the orthodox approaches which result in the introduction of the "finished", adapted varieties, the difficulties of such attainment would be considerable. Little organised plant breeding can be done *in situ* under the present conditions of scientific organisation and finance, and any proposal of initial work to be done from outside would still require the selection and testing of breeding material over the wide range of environments which constitute the occupation areas of native cultivators. The different nature of the agricultural systems and the terrains does make difficult the application of normal field plot techniques in both spatial and time perspectives. The following, then, is a suggested modification of procedures which incorporate the modern approaches with the selective procedures of the peoples in question:

1 *The Definitions.* Some of the plant characters that fit the contexts of areas, ecological and utilisational, have been suggested. The necessity for further definitive research, however has been indicated, including issues of plant pathology. The role of pests has not been mentioned, but the presence of both leaf and root predators has been observed in field work over the whole Pacific area. These definitions should be applied to the collection to assess the breeding possibilities over the broad base of requirements in the species. While the South American collection appears to have the most promise, there is sufficient transgression from that variation in some of the other populations to suggest that new genes or at least new combinations may have been evolved due to relative isolation of the populations after initial introduction.

2. *Plant Breeding.* Since most characters in the sweet potato appear to be inherited quantitatively, modern directive breeding techniques should be applied to concentrate gene blocks which contribute to the manifestation of desired characters. The physiological control facilities now available could be put to use in the preliminary laboratory testing of such combinations by growing them in the simulated light and temperature conditions of the areas for which they are intended.

3. *Field Selection.* The introduction of a range of these combinations directly into the hands of indigenous agriculturists may have two expected results: The selection of clones immediately considered desirable, and the testing of these by empirical observation. Horticultural curiosity ensures such observation over the range of environments and agricultural practices that ensue in given communities; the succession of testings under such conditions exposes the clones into the sexual reproductive cycle of the plant, with subsequent contributions into the local gene pool of desirable adventive genetic material. The combination with local adaptations may give enlarged scope for the selective talents of the native selectors.

There is now considerable substantiation of the exploitation of seedling sweet potato varieties in such agricultures. In the earlier phases of this work, the occurrence of true seed led to the suggestion that this provided the sources for the accidental discovery of seedlings (Yen, 1960). That there is cultural awareness of the source of such new varieties, if not the actual mechanics of their production, has been made obvious in subsequent field-work in the Philippines and Oceanic islands, where records of new varieties with descriptions of their seedling leaflets on first discovery. These are lent support by the specific observations of Bulmer (1965) in the western and eastern highlands of New Guinea. The practice of selection is further reflected in the categorisation of varieties by the western highlands informants of Bowers (1965), into those which grow well and those that are never planted in the high altitude gardens of the Kaugel Valley. Two of three varieties cited as examples of those adapted to high level growing proved to be among the most cold-tolerant in the collection in the New Zealand test. This is a small, but significant indication of the functionalism of native selection.

On the other hand, the suggested procedure takes advantage of the asexual propagating method applied universally to the plant, for selection by elimination, with concurrent growing of the local forms, may negate immediately and thoroughly, any mistakes that might be made in new introductions. Were the plant obligately sexual and cross-fertilising in breeding habit, there would be far less room for unpredictable error.

CONCLUSION

The plans for the development of indigenous areas and peoples seldom consider subsistence agriculture as an integral part of a contemporary economic system. Barrau (1958) is one of the few to suggest that some stress be placed on this aspect. In some Pacific islands, the subsistence systems have been virtually replaced by cash and plantation cropping. This replacement has brought with it some problems — in native nutrition; the imbalance of transitional-type economics which provide labour without the increase of capital; the erosion of social institutions, many of which were the cohesive forces for agricultural organisation in earlier times. The conservation of subsistence forms of agriculture, in their internal function of local food supply must be considered an important part of any future designs in guiding the evolution of viable economic systems. "Conservation" as used here has a connotation of progress, for it considers assistance that may be afforded by modern scientific endeavour in folk contexts.

The latter portion of this paper is a minor and indeed, hesitant essay towards a contribution in this direction.

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DISCUSSION 2

Prof. Harland :

Dr. Yen's paper is now open for discussion.

Mr. Williams :

Dr. Yen, in our paper we made fairly prolific references to your work in the Pacific, and on your collections of sweet potatoes throughout the world. I would like to ask you if you detected, in your collection of Asiatic and Pacific origin any trend towards a change to pin homostyly in the sweet potato as compared with collections from the Americas.

Dr. Yen :

No, I am afraid not. In the larger collection no skewed types of distribution were detected. We do not have any significant distribution geography-wise in the character.

Dr. Hernandez :

Dr. Yen, I would like to ask you first what percentage of the seedlings have carotene pigment in the fleshy roots.

Dr. Yen :

I have forgotten the exact percentage but what I can tell you is that we had high coloration in many clones.

Dr. Hernandez :

How high is the highest you would estimate.

Dr. Yen :

I would rather not quote from memory.

Dr. Hernandez :

Do you think that our genetic range of variability is higher in your collection than are normally obtained in a good progeny of seedlings ?

Dr. Yen :

I would say 'Yes it is.' But what comes out of the addition of more varieties to the collection is the kind of distribution which we get. We were formerly inclined to get normal distribution with the means just shifted. Now, with the greater collection, we have a rather altered situation where in some characters we are getting a kind of a skewing. Then you really see something of difference.

Dr. Jelliffe :

I feel somewhat out of my waters as I am a Pediatrician, but children live on root crops and I thought that I could comment briefly on Dr. Yen's excellent paper in which he introduced the dimension which I think I would like to emphasise and re-emphasise. He mentioned a particular community in New Guinea where they lived almost exclusively on sweet potatoes and he stressed the fact that these people, their protein intake and indeed their intake of all nutrients virtually are dependent on the quality of sweet potato. I would just like to introduce the note here, that in relation to the prime problems of human malnutrition which exists in young children, the same principle applies all over the world or in all developing and less fortunate parts of the world. I would like to re-emphasise the principle which Dr. Yen has stressed. When one thinks of the selection of particular types of food crops, including root crops one should bear in mind the fact that they may be the sole source of most of the nutrients for adults, and particularly for children. Therefore, when one comes to selecting a particular characteristic, I would suggest that the nutrient content, and in particular protein content and the amino acid composition, should be kept perhaps more to the forefront of our thoughts than perhaps has been the case in the past.

Dr. Magoon :

Dr. Yen, regarding some of the breeding procedures that you have listed re vegetative mutants, which are commonly distributed in sweet potato, would you think that we can advantageously increase their number through irrigation methods or possibly through the use of chemical mutagens ?

Dr. Yen :

The role of chemical mutants I avoided because I have never worked with them. But surely this is a possibility.

Prof. Harland :

The point raised by Dr. Jelliffe seems to be so important that I think that the meeting would be interested to know something about the possible range of protein content in the collection which Dr. Yen has made. It is probably the largest collection ever made in the world. Also, has he any information about the amino acid composition of the protein.

Dr. Yen :

I am very sorry Dr. Harland that we have not done any work in this collection of ours on protein, amino acid, or any crude protein figure with nitrogen or anything else.

Dr. Martin :

I would like to ask two questions. The first question is — Where is your collection currently located, and if people were interested in getting examples, where could they get information about variability and so on ? And where could they get actual materials ?

Dr. Yen :

The location of this collection is at present in Auckland, New Zealand. It is maintained in a glass house. This is because of the difficulty of storing tubers and getting them at all in some of the varieties. We have had to adopt this technique of vegetative maintenance. The actual obtaining of these is quite simple. I do not think that we have missed out as yet on anyone who wants material. For example, if you ask for some compatibility group we could not give it to you, but, if you asked for certain types of sweet potato we could send them and this has been done now, I think, for seven years.

Dr. Martin :

The other question I have refers to an unusual morphological feature in the sweet potato. In open pollinated or breeding progenies, a new type of vine occurs. It climbs like a Morning Glory, and of course, this trait has not found a use in the western world. But I wonder if, in your collection of sweet potato, you have run into this in fields of mixed varieties.

Dr. Yen :

I could describe all kinds of curiosities in this species, which I collected as cultivars. As far as climbing is concerned, we have a number which will climb when they get older. I say when it gets older, meaning that it may just be a coincidence, but it may be time of growth, or response to cold temperature. But certainly at the later stages of growth we get quite a few varieties showing a twining character. However, we have one from Ecuador which has a climbing propensity throughout from the start. We have tried it on stakes but we still had to help it up. In my field work among native peoples I have struck quite a few individual vines which climb right up a fence. But I do not know why. We tried to use this character in the variation study. However, we were unable to do this because there is a low frequency of plants that showed definite ability to climb.

A COMPUTER-AIDED MORPHOLOGICAL CLASSIFICATION OF *MANIHOT ESCULENTA CRANTZ*

— *by* —

David J. Rogers
Colorado State University

The following classification is based on the collections made by the author in the more important growing areas of *Manihot esculenta* in the Western Hemisphere. It is a classification of the cultivars, and does not indicate the relationship of the species as a whole to other members of the genus *Manihot*. The classification does not employ herbarium specimens made by other collectors because the typical collections are not adequate for the purposes of differentiation of the cultivars of this species.

The classification is based on 231 population samples, carefully selected from over 500 samples made by the author. These 231 samples represent the most complete of the collections, and contain amongst them the major morphological variations to be found over the geographical range of the species.

Samples were made in Jamaica, both from private holdings and from the extensive collections of the Department of Agriculture's experiment station at Bodles, near Old Harbor. In Costa Rica, collections are from private holdings and from the collection established by Dr. Jorge Leon at the Inter-American Institute of Agricultural Sciences, Turrialba. In order to provide a check on the stability of characters employed, these two areas were sampled at least twice in separate years. Other collections were made at the Federal Agronomic Experiment Station of Brazil at Belem, Para, the collection of which was assembled from the Amazon Basin by Dr. Milton de Albuquerque; from the state experiment station of Tambe and Ararapina in the state of Pernambuco, both stations under the over-all direction of Dr Jaime Coelho; from the Federal Agronomic Experiment Station at Sete Lagoas, state of Minas Geraes; at the state experiment station of Sao Paulo, in Campinas under the direction of Dr. Edgard Normanha; at several private locations in Bolivia and Peru, and along the Amazon River near Manaus. Collections from nearly every major growing area in Central and South America have been examined, and if possible, specimens included in this study. It is felt that most of the types of variation existing in this complex has been sampled.

The classification is based on morphological criteria alone. While it is regrettable that biochemical and cytological information are not included, this first survey of the species in its various areas of distribution could not, because of the practical problems, include these types of information. Clearly, it is important to include this type of data as our knowledge of *M. esculenta* expands. It is hoped that this morphological classification will be accepted for its intended purpose—a method by which various morphological types within the complex can be identified, and by which workers from various places can relate the plants of their collections to those of other areas.

It will be noted that no collections from other important regions of the Eastern Hemisphere tropics have been included. Since this plant is of Western

Hemisphere origins, it was felt more critical to study the plant in its native areas of distribution first, and to perhaps later expand the work to those areas where the crop is an evident introduction (cf. Rogers, 1963, 1965).

CHARACTERS EMPLOYED IN THIS STUDY

Tables 1 and 2 illustrate the information upon which this classification is based. From an examination of these characters, it becomes evident why the typical herbarium specimen of the botanist is not satisfactory for this type of classification. The samples I made consistently included materials which would make it possible to make comparisons of these parts of the plant most important to the cultivator, the roots, plus other obvious parts of the stem and leaf. Note that no information is gathered for the flowering parts of the plant. This is done because many cultivars do not normally come to flower by the time the plant is harvested, and the information about the flowers, while critical to a classification within the genus *Manihot*, is not critical to this classification among the cultivars alone. From my examination of the flowering material of many cultivars, I do not feel that the morphological characters of the flower vary significantly. It has been found by Moh (1966) in Costa Rica, that there is considerable variability in pollen viability, and this no doubt is an important feature to be kept in mind when breeding considerations are made.

COMPUTER PROGRAM

The methods employed to provide an objective classification of *Manihot esculenta* are described in a series of papers (Wirth, et al 1966; Estabrook and Rogers, 1966; etc.) and the program itself is available to anyone interested in using the methods. A more detailed description of the computer methods will be presented in the demonstration on Tuesday afternoon. At this point, only a cursory description is given of the methodology.

For each sample, a recording is made of each of the characters given in Tables I and II. All samples are treated in the same way. From these character records, a measure of similarity between every sample is computed by taking the fraction of the characters for which both samples possessed the same attribute. Thus, relations between all objects are produced, in a measure of over-all similarity. The method used has been designated by some workers as the simple matching coefficient.

The similarity table generated in this step is used as input to a procedure for clustering the objects. The model used as the mathematical base of this particular clustering method is derived from graph theory. A series of "subgraphs" of the samples under study can be made, each subgraph connecting samples with a certain value of similarity, and partitions between the different connected subgraphs. By lowering the similarity values, a greater number of samples are joined by subgraphs and we eventually place all objects into a single subgraph but along the way, pick out groups of organisms which satisfy certain requirements. This procedure is best illustrated by the following, over simplified diagrams (Figs. 1-5).

DESIGNATION OF THE GROUPS

We have chosen not to erect any formal nomenclature for the clusters of interest to us. Since the purpose has been to show the "constellations" of morphological expressions, and to give some means to differentiate amongst an essentially reticulate relationship, we have not felt that any formalized names could be adequately applied. Therefore, we designate our clusters as "groups," and number them with Roman numbers for convenience in discussion. This convention is flexible.

One may discover many interesting inter-relations by using the computer program, and many more than I have time to indicate in this discussion. There are several ways in which the results of the graph theory model give useful information. In addition to the delimiting of clusters or groups, the method indicates how widely divergent one group is from another—how much morphological isolation one group has from another —and also which samples of one cluster act as linking agents to another cluster. In this latter case, the most likely hybrids between groups are indicated—that is, which samples in one cluster have the most properties in common with samples in another cluster. This gives the worker some idea of the nature of the variation types within any cluster, a useful indication if he wishes to develop some breeding program.

But perhaps the most useful attribute of the computer program is the fact that many different ideas about relationship may be tested. If one wishes to discover the influence of a certain new piece of information on an old classification, the computer is sufficiently rapid that the test can be made in a short enough time to allow several tests of ideas. We must not assume under any circumstances that the computer "tells you" what you must do, rather it is used as a tool to aid our idea-testing.

THE GROUP OF M. ESCULENTA

The graph-clustering procedure for 231 samples of *M. esculenta* was completed in 101 levels, and all samples were placed together in a single cluster at the similarity value of 0.62500. In examination of the intermediate levels, we discover that the population was essentially divided into clusters at the 59th level of clustering, similarity value of 0.81875 with two major sets of characters. The clusters we can form at this level are indicated in Fig. 8, showing the primary division of *M. esculenta* into subequal groups which we designate as "rough" and "smooth" rooted. Note character number thirteen. It can also be demonstrated that these groups are differentiated as well on the external root color and external stem color—those with "smooth" surfaced roots are light tan or pink, and have silver-colored stems; those with "rough" roots are brown to dark brown or brown-yellow, and have brown, yellow, or infrequently silver-brown stems. We feel that these characters are sufficiently constant to provide a major division within the species complex. No geographic differentiation accompanies this division, and to the author's knowledge the plants with these characters occur in about the same proportions in all areas sampled. This being the case, no subspecific definition in the sense of wild-plant taxonomy, is possible, for this taxon is usually designated as allopatric. In the past, I have proposed that the term "convariants", used in regularly recommended nomenclature for cultivated plants be used in designation of these two, but do not feel that this is justified.

The smaller number of plants (or cultivars) belongs to the group designated smooth. But the same type of variation in HCN content occurs in plants of the smooth-rooted group as occurs in the larger, rough-rooted, group of cultivars. It is also true that characters other than the HCN content of the root vary equally in both the smooth and rough-rooted groups. For these reasons again, I do not feel justified in making a formal taxonomic category. We are more interested in the morphological variations, and ways to identify them, than a classification for the sake of some finalized botanical nomenclature.

FURTHER GENERAL SUBDIVISIONS

It will be noted in the breakdown given in Fig. 6 that both the rough and smooth-rooted varieties are subdivided into two groups, each with the mnemonic, descriptive terms, "linear-lobed" or "obovate-lobed" groups. These groups remain separate until about a similarity value of 0.75, which would indicate that about 3 to 4 characters out of 15 differ between them. When there is this much difference, we have more confidence that the groups have some validity, and are not based on a single character difference, or, in other words, are not based on purely subjective judgment, as would be the case without the computer analysis. These groups have more internal connections among themselves than with the groups outside,a fact that is best demonstrated on the computer print-out.

Below this level of subdivision, and within each of the above named breakdowns (linear-lobed or obovate-lobed) we reach the lowest categories that we wish to circumscribe for the purposes of classification. Each of these groups, designated by Roman numerals and lower case letters, constitutes a number of cultivars which for convenience' sake have also, as for the larger groups, been given a morphological, informal, epithet. These divisions are still capable of being recognized as groups, but their relationships among themselves are more complex than the larger divisions due to their reticulate nature. The lowest level of similarity that can be demonstrated for these is about 0.80. In other words, any organisms showing less than this amount of similarity to the other, included, organisms, should be considered as a separate entity. This might be the case if we were dealing with separate species, but since these are cultivars within a single complex species, we have not felt bound to continue separations, although a relatively small number of cultivars are much less similar than the 0.80 figure. It is not the purpose of our classification to split down to the individual cultivar. Let it be said, however, that the computer method allows each organism to be related to all other cultivars with accuracy, as will be shown in the following discussions.

By far the largest number of cultivars fall into the category of rough roots, with brown, yellow or reddish brown stems. Within this group, the preponderance are obovate-lobed (Fig. 6). Our subgraphing technique indicates that there are eleven subdivisions within the obovate-lobed, rough-rooted group. It is a matter of choice whether we will accept still other categories at this level, but we feel that if we follow a set of rules to delimit them, that we must not designate more than this. My meaning on this point will be explained in some detail below.

THE SMOOTH -ROOTED, SILVER-STEMMED GROUPS

Since the time limitations on this paper do not permit a full exposition of the classification of *M. esculenta*, we will concentrate our attention on the smaller of the large subdivisions, in order to demonstrate the rational for the classification (Fig. 7).

As noted above, the silver-stemmed, smooth-rooted group can be divided the same way the rough-rooted group is divided, namely: linear- or obovate-lobed. There are no sharp or deep "moats" within the cluster of linear-lobed cultivars. They are not particularly closely related, inter-alia, but their relationships clearly differentiate them from the obovate group. The differences between the clusters of linear-lobed and the obovate-lobed are noted in the accompanying Fig. 7. The obovate-lobed, smooth-rooted group obviously has the larger number of subdivision, as was the case in the rough-rooted group.

We will take the groups in the order given. First, the linear-lobed smooth group may be characterized as follows: the roots are externally light brown, tan, or light tan, and a few are light pink; the root cortex is white to cream and rarely yellow, but there are no pink pigments in the cortex. The leaf-scars on the stem are usually slightly to moderately raised, seldom large. The lobes of the leaves are moderate to long, and most frequently are sinuate-margined. The petioles are usually green, but may be red-green, or rarely red. The linear-lobed, smooth-rooted group tends toward little or no branching, with few cultivars fully branched.

Figure 8 illustrates the inter-relationships among the 17 cultivars included in the linear-lobed group. The boxes enclose cultivars related above 0.85 similarity, and nearest-neighbors are immediately related within smaller boxes. The "core" of linears include those listed from 114 to 225 (numbers of cultivars are my collection numbers). Two closely-related, but separate, "strings" are attached to specimens numbered 303 and 300. Outlying individuals are connected to the center core. All connections indicate (by a bracketed number over the lines) the similarity measure which join the specimens. Arrows indicate the specimens within this group which are closest to members outside the group. Interestingly, both specimens (114 and 131) join to the same group in the obovate-lobed cluster, and at the same similarity value. The secondary connections betwen objects have not been indicated on this diagram, but a very useful summary of the 10 closest objects is given by a part of the computer print-out called the "nodal distance array." We have used the diagramming technique of connecting only closest neighbors because of the nature of the biological relationships with the species *M. esculenta*. Were we to indicate all the relationships that each specimen has with all others of the complex, we would lose sight of the major objective of a classification, namely, the placing of an individual in a grouping which the worker can visualize. Other groups of organisms tested with our method indicate that other application techniques with the computer print-out are valuable. This is, the nature of the variation to be found in different genera and families, obviously, is not identical with that found in this species, this genus, or perhaps in this family. For example, computer studies of a section of the genus *Cassia* done in collaboration with Dr. Howard Irwin of the New York Botanical Garden indicate that the most important part of the print-out was that dealing with the internal connections within the clusters. In *Cassia*, the connectedness within a cluster was a measure of the "goodness" of the species. Certainly the amount of connectedness within the species *M. esculenta* is no measure of, nor indicator of, the goodness of this or that cluster.

Looking back at Fig. 7, we see the structure for the larger group of smooth-rooted cultivars, here designated II, obovate-leaves. This designation actually refers to the lobes of the simple leaf, and all characters—length, width, margin, etc.,—are of the central lobe. Group II has five subdivisions, whereas the equivalent group (IV) in the rough-rooted category was divided into eleven. Obviously, there is no real equivalence in these subdivisions of obovate-lobed groups between rough-and smooth-rooted cultivars.

The same rules apply—as with the cluster of linear-lobed cultivars—all connections between pairs shown is above 0.80. As with other groups, this does not indicate that all specimens included in a cluster share the same or higher similarity values. Rather, as indicated earlier, most of the relationships found in these clusters are clinal, with the ends of the clines having little in common. But the clusters are not particularly well described as clinal, since the implications of a cline are frequently some geographic distribution, and we cannot assign any of our larger groupings to be specified geography. Part of the explanation is the fact that many of my specimens were made from experiment station collections, from diverse areas, and did not necessarily represent any one local area, as the point where I collected it.

Figures 9 through 12 represent the four groupings of obovate-lobed, smooth-rooted plants. We have given each of these a morphological name for the most obvious common trait. IIa, unbranched, (Fig. 9) has a specimen (No. 120) from which most of the variations are derived. In this case, 120 acts as an articulator, holding together a group of smaller clusters which would otherwise not connect.

Figure 10 illustrates that the group IIb can be subdivided. In this case, we have indicated the points of the other clusters to which this cluster joins. Also indicated in IIb_2 are the points where cluster I, the linear-lobed group joins, and the similarity values at which they join.

Group IIc (Fig. 11) contains the largest, and perhaps the most common set of morphological conditions to be found amongst the smooth-rooted group. If one were working in a "typological" manner, one would select group IIc as the type for the smooth-rooted clusters. However, we are aware of the hazards of such a designation, and only point out that more specimens fall in this category than in any of the others.

The last of the smooth-rooted group, IId, (Fig. 12) contains two specimens 229 and 301, whose character-combinations indicate one of the major difficulties with assigment of a morphological name to designate the group. These two specimens are clearly 7-lobed, but according to all other characters, should be associated with group IId. While the assignment is good, according to the over-all similarity measure, the naming of the group is poor. But to give another morphological epithet to the group would require a polynomial designation. This is as unsatisfactory as the name we chose, and much more cumbersome.

This group also illustrates the point made earlier, that the similarity measure can drop below 0.80 and still include specimens adequately assignable to the group. The two specimens are 329, paired with 365 at 0.69 similarity, and 316, paired with 119 at similarity of 0.67.

SUMMARY

We have summarized the variation in *Manihot esculenta*, and discovered a satisfactory method for dividing the cultivars into related constellations. The relationships amongst the cultivars is reticulate, but by employing the graph theory model, we have been able to discover the major categories, and found that the recognizable groups are "strings" of clinal relationships. There will probably be some variations to the groups we have established, particularly when new biochemical information is found, but without the addition of further information, we are certain that an investigator can reliably relate his materials to the categories we have provided.

The classification is based on the collections made by the author, and no other herbarium material has been employed to structure the classification. The specimens used in this classification will be housed in the herbarium of the United States National Arboretum, central locality from which other interested workers may borrow these materials

Table 1

Manihot esculenta characters — January, 1967

STEM CHARACTERS, Nos. 1, 2, 14, 15

K_1 Color of Stem

1. Silver   N = 6
2. Silver-brown   K = 1
3. 0
4. 0
5. Brown
6. Yellow

K_2 Branching of Plant

1. One branch at top or no branches
2. One or two branches but not 1 branch if at top
3. More than 2 branches

LEAF CHARACTERS, Nos. 3-10

K_3 Leaf Lobe Shape

1. Obovate
2. Linear

K_4 Number of Lobes of Leaf

1. 3 or 4 lobes
2. 3, 4 or 5 lobes
3. 5 or 6 lobes
4. 4, 5 or 6 lobes
5. 7 or 8 lobes
6. 9 or 10 lobes

K_5 Length of Median Lobe

1. Less than 14 cm
2. 14-17 cm
3. Greater than 17 cm

K_6 Width of Median Lobe (widest point)

1. Narrow (1.5 cm—2.4 cm)
2. Medium (2.6 cm—4.8 cm)
3. Broad (5.0——————)

K_7 Sinuosity of Lobes of Linear Leaves

1. Pandurate
2. Some sinuosity
3. Simple (not sinuous)
4. Logical (obovate)

K_8 Sinuosity of Lobes of Obovate Leaves

1. Pandurate
2. Some sinuosity
3. Simple (not sinuous)
4. Logical (linear)

K_9 Color of Young Foliage

1. Reddish-blue
2. Bluish-green
3. Green

Table II.

K_{10} Petiole Color

1. Red
2. Green-red
3. Red-green
4. Green

	R	GR	RG	G
R	1			
GR	75	1		
RG	25	75	1	
G	0	25	75	1

ROOT CHARACTERS, Nos. 11, 12, 13

K_{11} External Color of Root

1. Light brown-yellow
2. Brown, dark brown, reddish brown
3. Light brown, tan, light tan
4. Pinkish brown, pinkish tan
5. Pinkish white, light pink, pink

K_{12} Cortex (root) color

1. White to cream
2. White to cream with pink
3. Cream-yellow to yellow
4. Cream-yellow to yellow with pink

	1	2	3	4
1	1			
2	75	1		
3	0	0	1	
4	0	0	75	1

K_{13} Surface of Root

1. Smooth
2. Rough

STEM CHARACTERS, Nos. 1, 7, 14, 15

K_{14} Nature of Scars on Stem

1. Smooth
2. Slightly raised — N = 4
3. Moderately raised — K = 1
4. Very large

K_{15} Storey Length

1. 4—8 cm
2. 9—20 cm
3. 21—28 cm

Fig. 1.

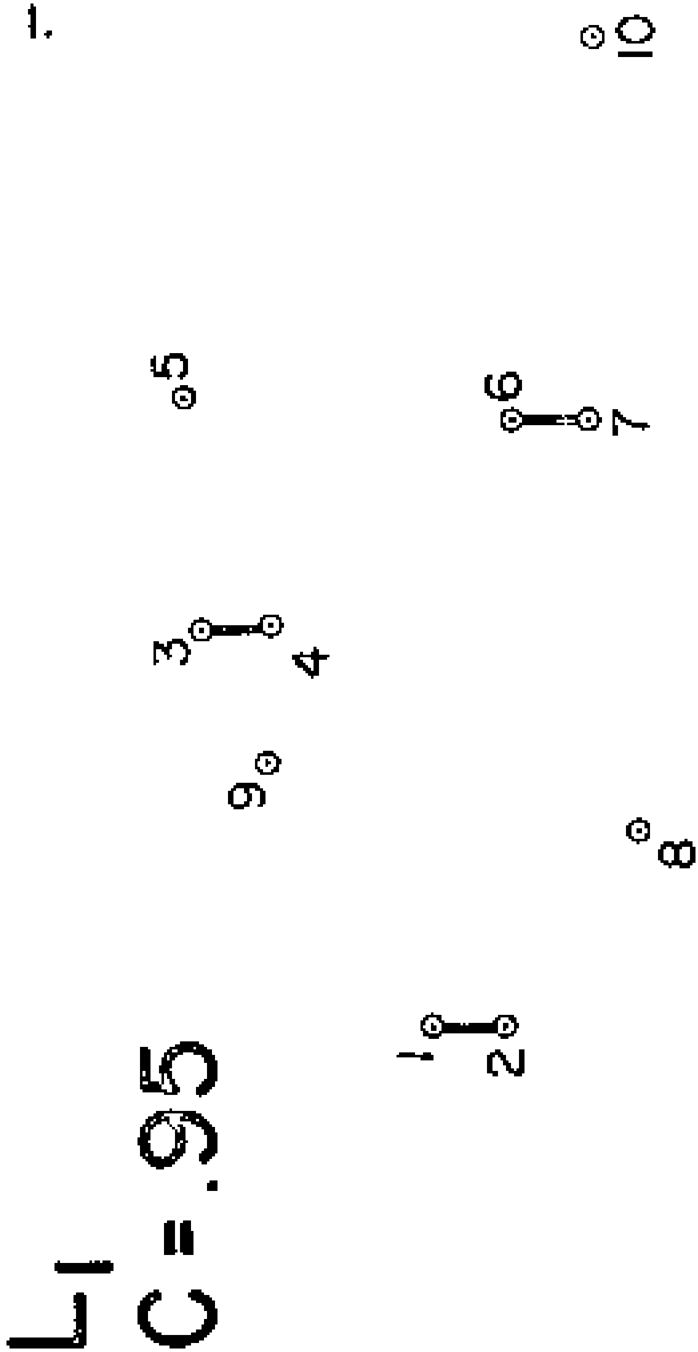


Fig. 2

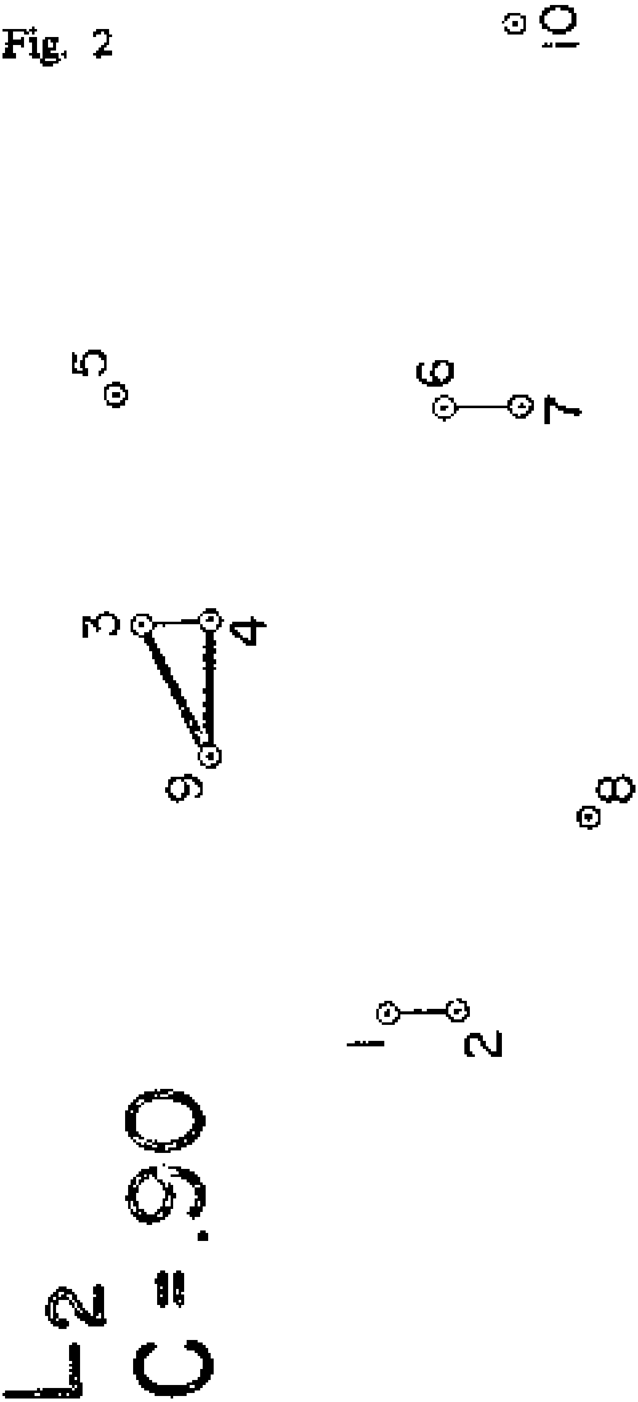


Fig. 3

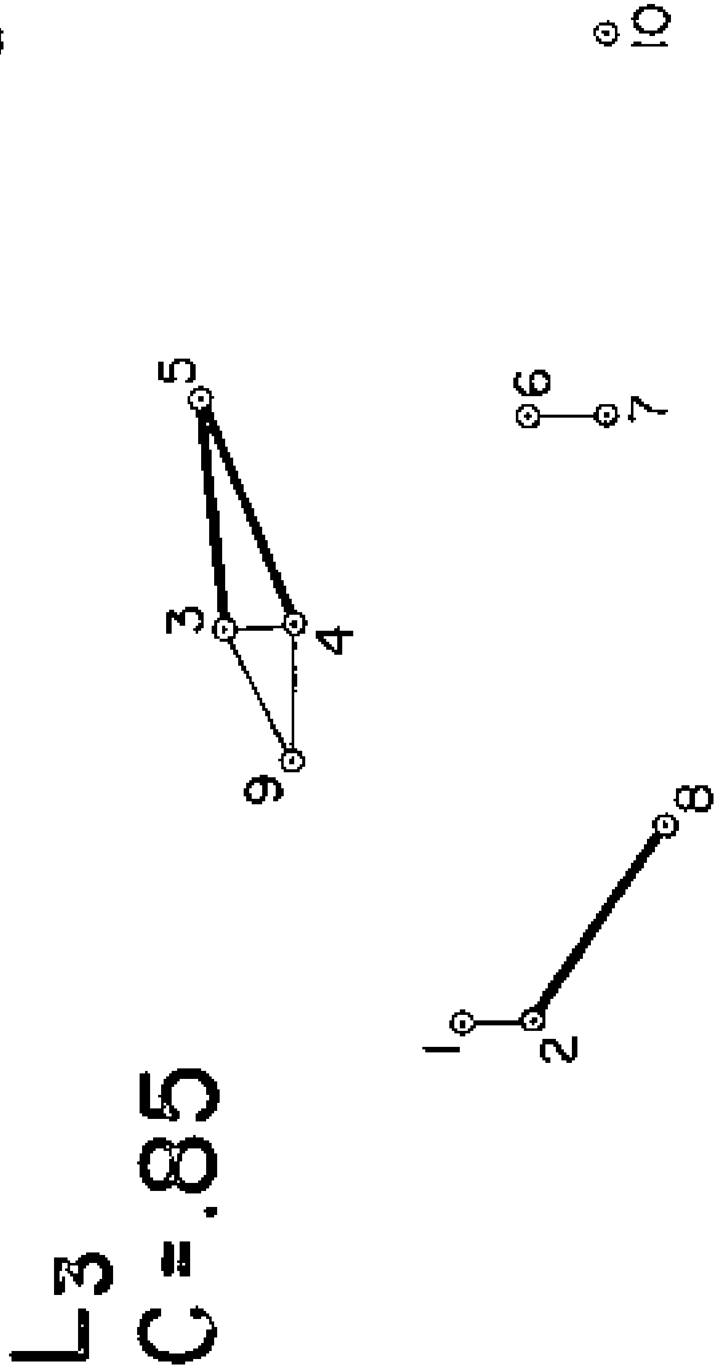


Fig. 4

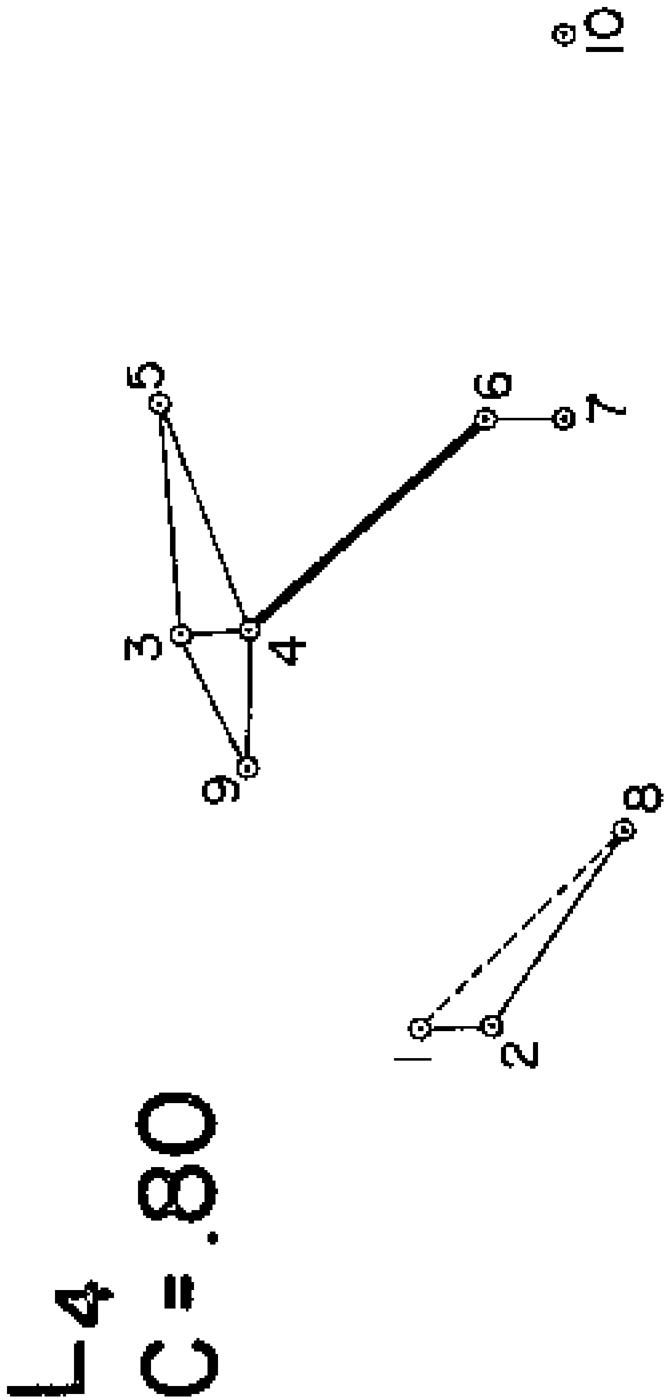


Fig. 5

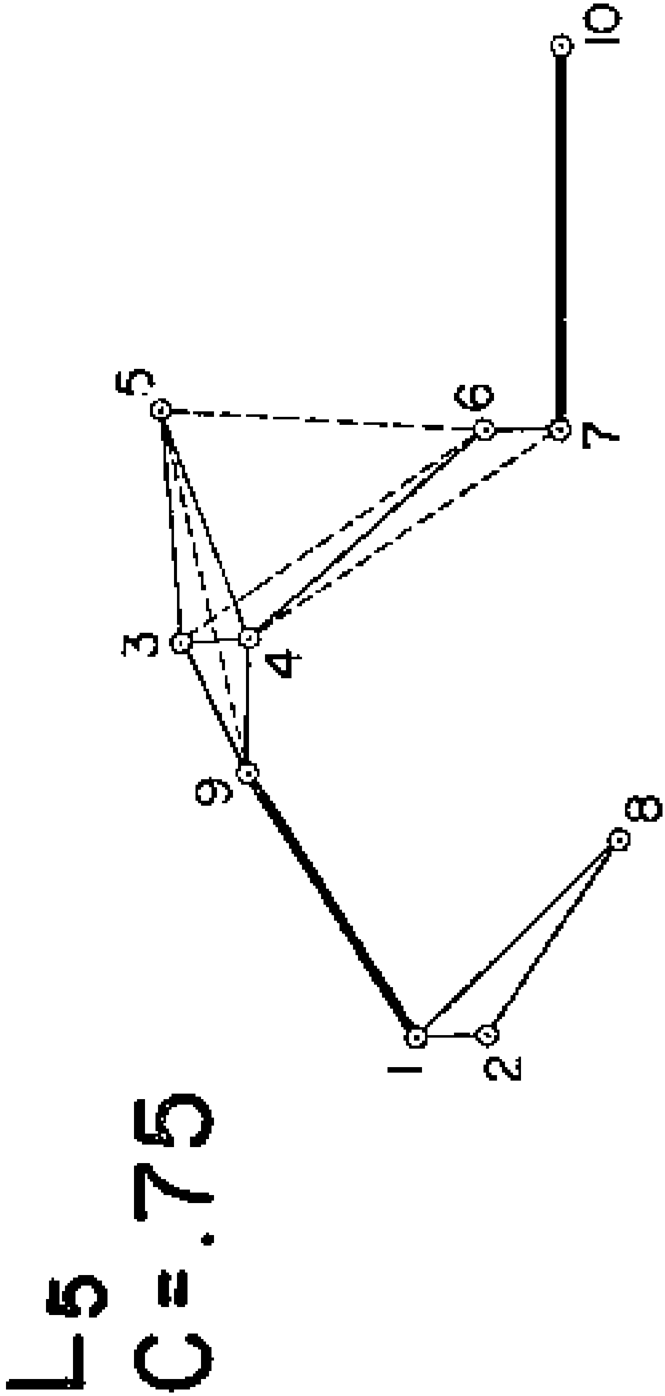


Fig. 6 Manihot esculenta, Crantz

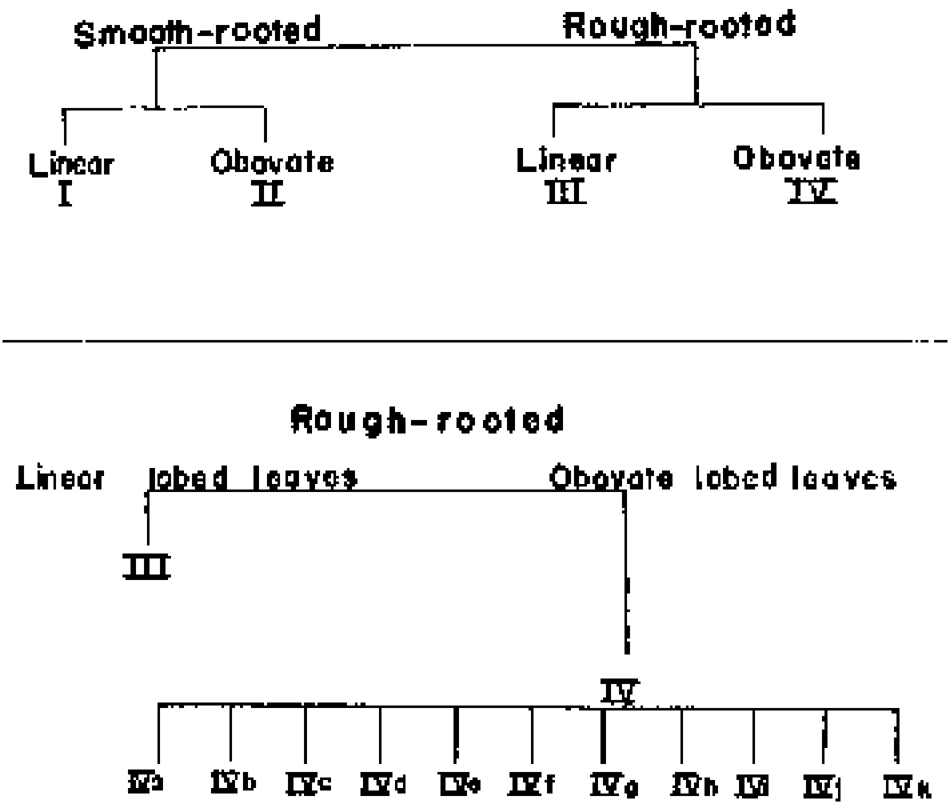


Fig. 7

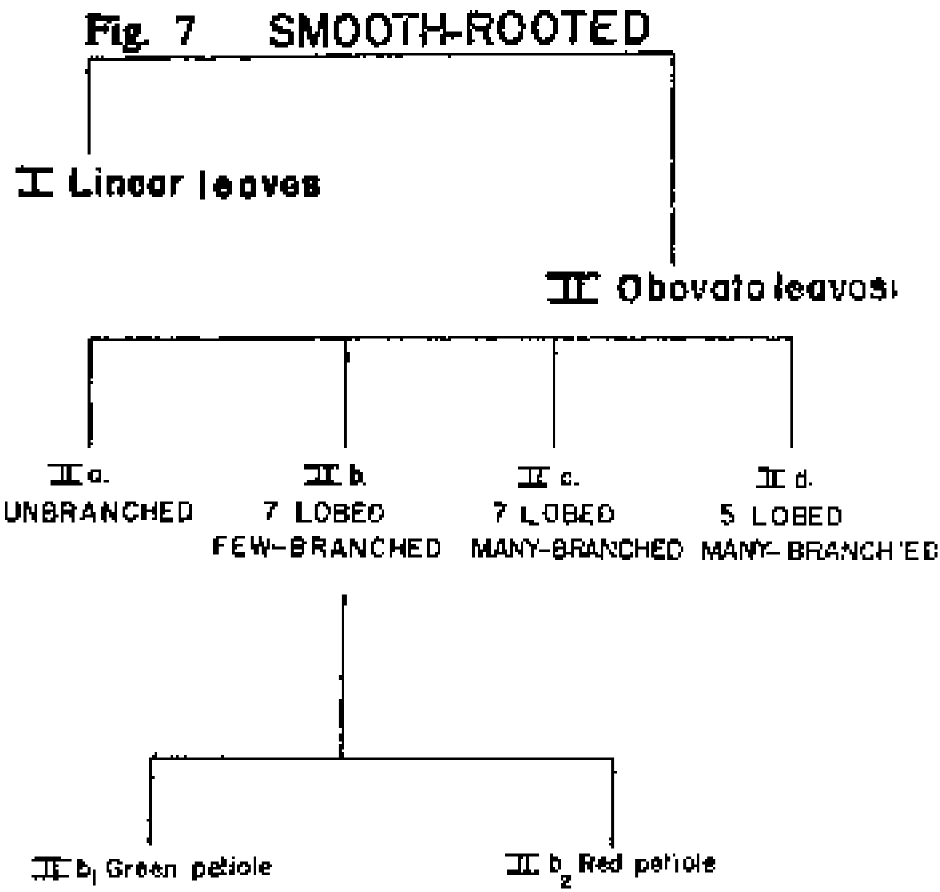
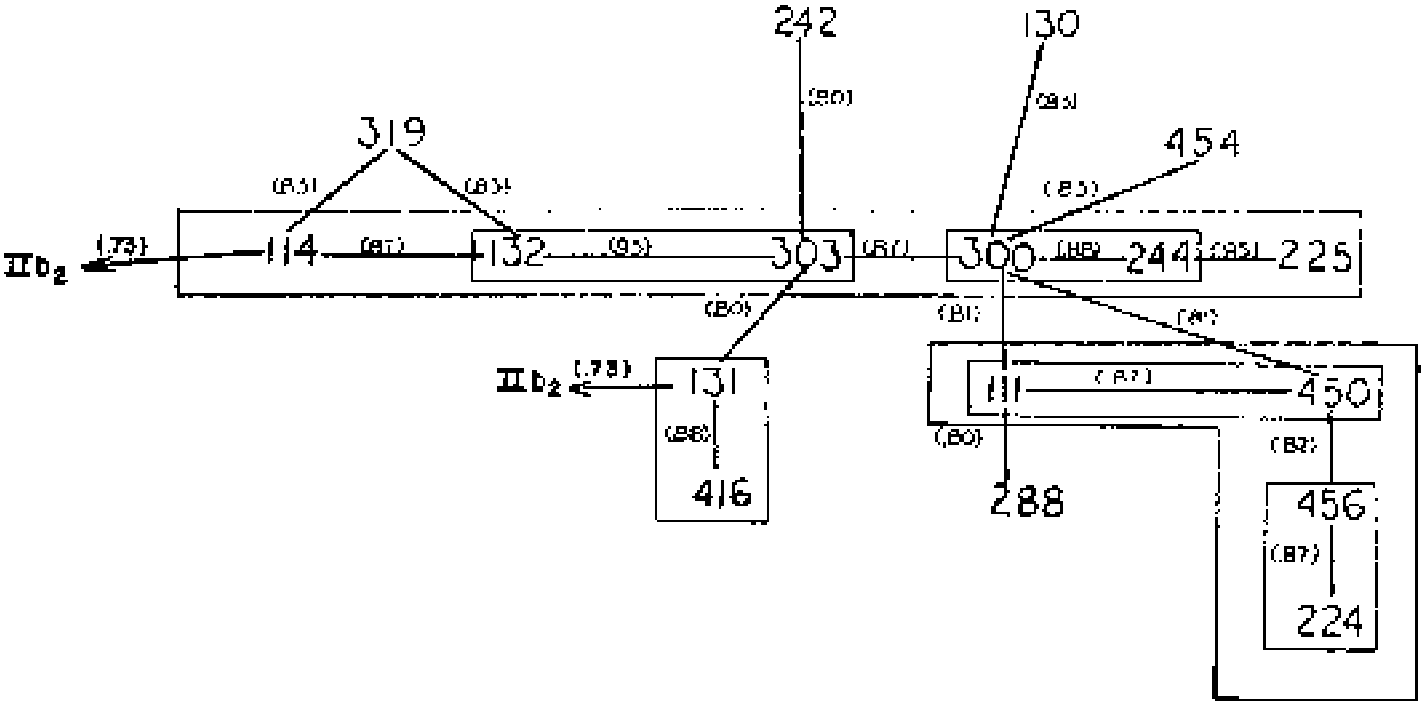

SMOOTH-ROOTED
I Linear leaves
II Obovate leaves
II a.
UNBRANCHED
II b.
7 LOBED
FEW-BRANCHED
II c.
7 LOBED
MANY-BRANCHED
II d.
5 LOBED
MANY-BRANCHED
II b1 Green petiole
II b2 Red petiole

Fig. 8 *Manihot esculenta*

Group I, Linear-lobed foliage



Group IIa, Unbranched

Fig. 9

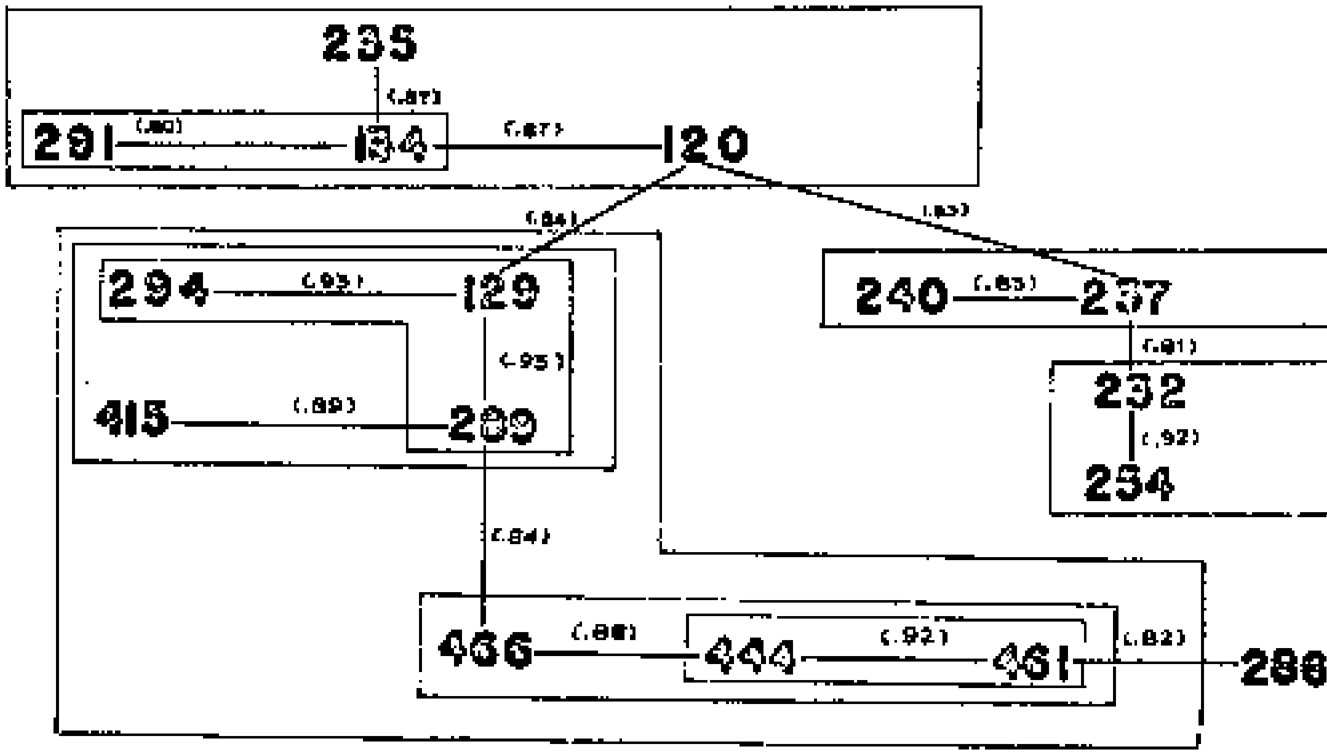


Fig. 10 Group II b, 7 Lobed, few-branched

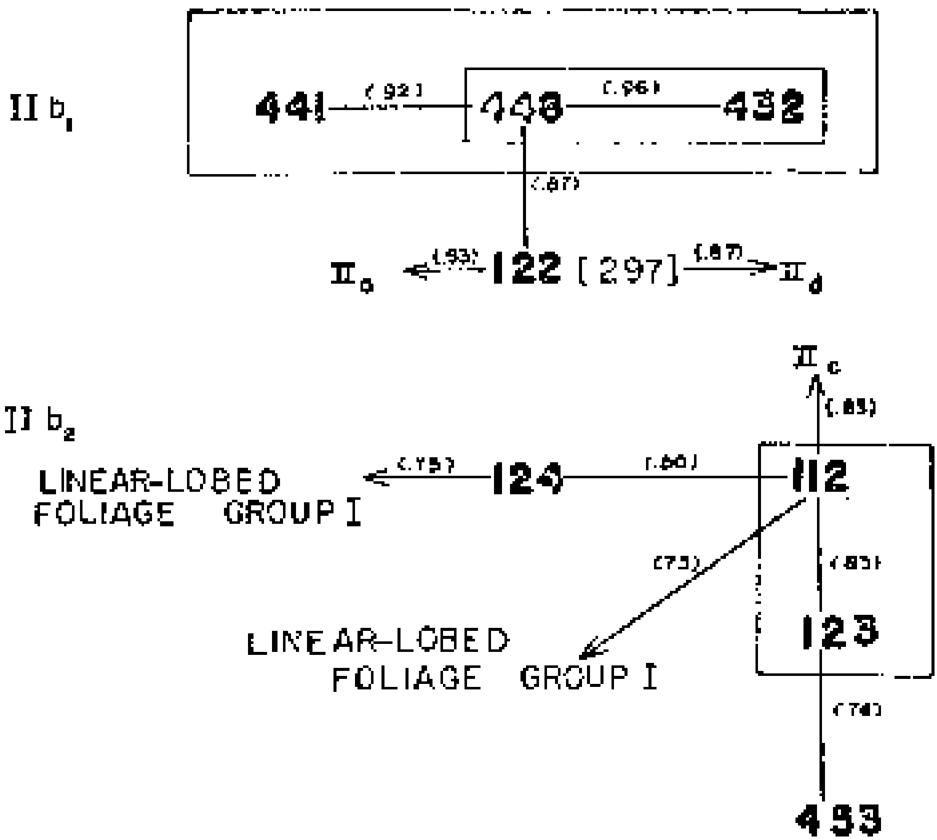
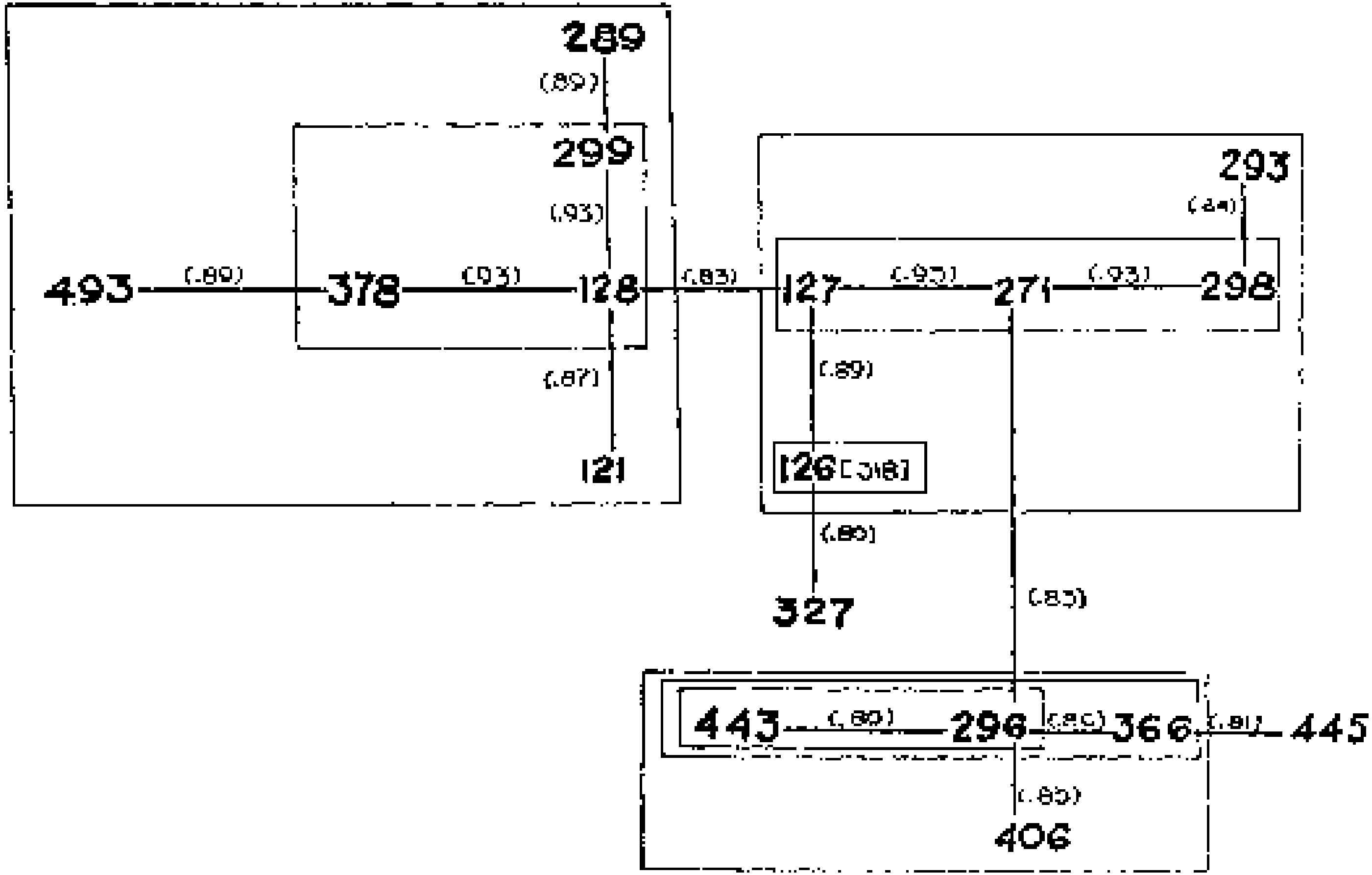


Fig. 11 Group IIc, 7 Lobed obovate, many-branched



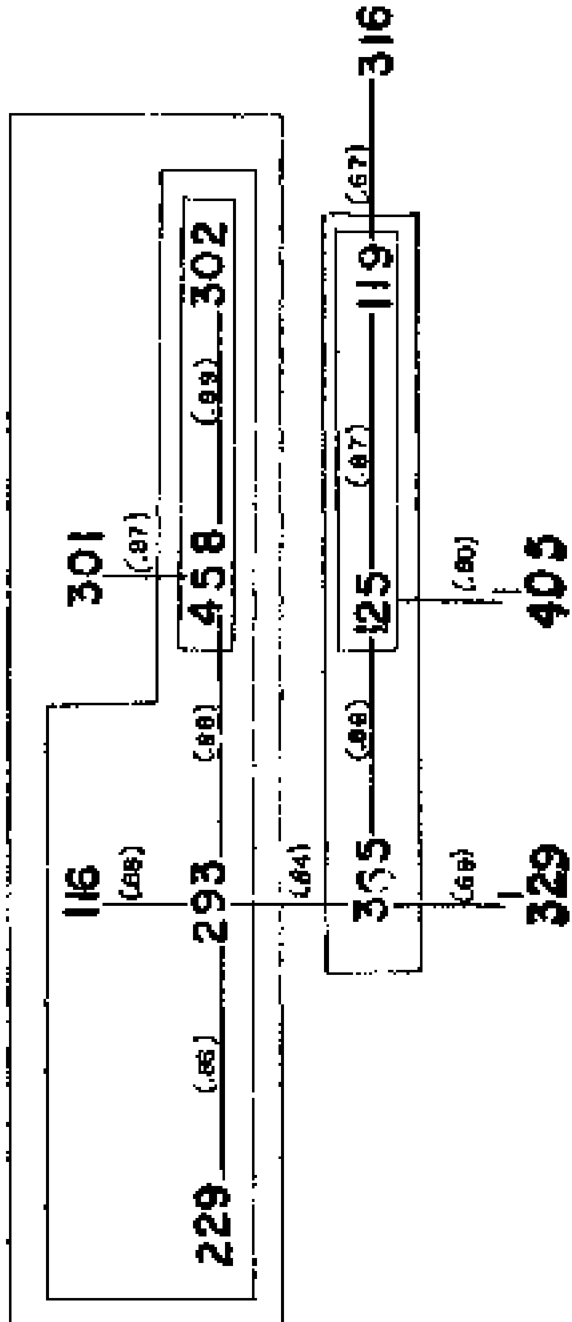


Fig. 12 Group II d, 5 Lobed, many-branched

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DISCUSSION 3

Dr. Magoon :

In my opinion, Dr. Rogers has done an excellent job in presenting a classification based on good morphological criteria and I am sure this morphological classification will be found useful for its intended purpose — a method by which different morphological types within the complex can be identified, and by which investigators can relate the plants of their collections to those of other areas. However, as you have rightly pointed out, that this is a broad framework, into which other data of a more experimental nature, for example, evidence from other cognate fields such as genetic, cytogenetic and immunochemistry etc., which can result in a more natural classification based on ancestral relationships, will have to be fitted. In other words, a combined study of morphological, cytological, genetical and other aspects, with a view to develop a comprehensive classification based on several criteria, is an urgent necessity and studies along these lines have already been initiated in this crop at our Institute as may be seen from the data presented in this regard in my paper. In fact, the potential importance of pachytene analysis and its wide application to several taxonomic, cytogenetic and evolutionary problems has been well realised. I have also described at length in my paper the various advantages of studying the morphology of pachytene chromosomes of the various cassava types and further, the approach adopted by us in classifying the various hybrids, based on the data obtained especially on the nature of chromosome pairing at mid pachytene stage as well as fertility data, is indeed sensitive enough to detect structural differentiation and incipient evolution in the cassava material under study and it would, therefore, be helpful, if such an approach, coupled with the approach described by you based on morphological criteria, is applied to the vast amount of germ plasm material at present available in the genus before lumping up the different taxa or rearrangement of the various taxa into suitable groups or sub groups etc. This will have to be further supported by genetical data, wherever possible. As you know, from the taxonomic point of view, it is probably of little significance whether 'species' distinctions are attributed to multiple gene substitution or to cryptic or small structural differences, but from an economic stand point it is an issue of prime importance. Upon it depends the degree to which a plant breeder can hope to transfer a character of potential importance from one species to another. If 'species' differences are mainly due to multiple gene substitution, the problem is chiefly a matter of growing large enough progenies to secure the required combination, whereas, the success with which a plant breeder can transfer potentially valuable characters from one species to another, will be inversely proportional to the frequency of small structural differences amongst his breeding material. Such an evaluation is of paramount importance since it would eliminate the loss of energy and time on the part of the breeder in launching a hybridisation programme indiscriminately.

Dr. Coursey :

I am extremely interested to hear of this technique, which I understand is being applied so far only to the American forms of cassava. It seems that this technique could be applied with very great value, to study the spread of cassava in the Old World. This has been an extremely interesting ethno-botanical problem involved here. To quote one example, although cassava has been in tropical Africa for three or four hundred years, there are many places, or should I say, some places, where it would perfectly well be cultivated and is now being cultivated in fact, but where it has only arrived in living memory. It seems to me that this technique could be combined with historical investigations, to form an extremely interesting study.

Dr. Rogers :

May I make one comment on that statement? I really did not want to say that my methodology showed any kind of relationship geographically, but clearly it does. I mean it is just to the point where I am not ready to make any specific statement about it. For example, in spite of the fact that Jamaican cultivars have been imported from other parts of the Western Hemisphere, they stick together as relationships, not only with the West Indian cultivars, but also with those along the northern tier of South America, from which they were largely collected. The morphological evidence supports this. The ones that I have collected from Bolivia, for example, have more in common amongst themselves, and stick together better than those from the Eastern side of Brazil. The Brazilian cultivars seems to hang together, the central America ones have a tendency to hold together. In other words, we have a very powerful tool in our methodology, which points to these interesting sorts of relationships. What they mean, and how they are going to be interpreted is yet for us to decide, but they are in line with what you are saying. We only need now to have input data from all over.

Dr. Doku :

We have attempted on a moderate scale to classify our cultivated varieties in Ghana, and we found an interesting character, that is, the height at which the plant branches. The primary branching habit, is either at one third of the plant's height, half way, two thirds or at the apex. Are your varieties consistent in this character ?

Dr. Rogers :

The branching of the plant is clearly co-ordinated with the flowering of the plant. In other words, when it branches it has flowered, so you can say that you have some validity to the character for branching, where you try to make this correlation. However, we discovered that there is a very large number of variations in branching pattern. It is not necessarily advantageous in the process of classification, to divide characters for branching into all of the states which are biologically interesting. At one time we had as many as 16 different states to the character of branching relating it to the time of flowering. When we tested them on the computer a completely smooth curve was obtained.

INTRA AND INTERSPECIFIC CROSSES IN THE GENUS MANIHOT

— *by* —

G. G. Bolhuis
University of Wageningen

As long as selection in cassava is limited to the testing of cultivars, seed production is not a factor of importance. It becomes, however, very important when in the case of breeding purposes, large populations of seedlings are necessary either from free-pollinated plants or from artificially cross-pollinated plants. In the latter case, especially, it is desirable that from hand operated pollinations are obtained as much fruits and from each fruit as much seeds as possible.

Koch (1934) in his thesis does not pay much attention to this problem and gives only a few figures. He mentions that in 1933 from 22,000 cross pollinations a total of 1500 fruits were obtained signifying a success of 7%. On the behaviour of the various cultivars used as parent clones nothing is mentioned. More data are given by him on the crosses between *Manihot utilissima* and *M. glaziovii*, but here the number of pollinations is so small that expression in percentages may lead to erroneous conclusions. The same objections must be made in relation to figures given by Nichols (1947). He notes that from his crosses between different cultivars, the percentages of success fluctuate between 0 and 56, with averages of 13.6 and 14.6 which have relation to respectively 27 and 32 crosses in the F_1 and F_2 generations. Nothing is said, however, about the behaviour of the different parent clones. He concludes that a low percentage of success is a striking feature within the species. In those cases where he got no success at all he assumes that incompatibility may exist.

In his interspecific crosses he generally finds low success and sometimes no success at all. With species hybrids he is sometimes faced with selfsterility. Back crossing with cassava-parent generally gave much better results.

MATERIAL AND METHODS

In the description of his crossing technique Nichols (1947) mentions that both male and female flowers are enclosed in muslin bags before and after pollination. Koch (1934) however, reports that pollination is effectuated by capping the female flower with a male one. The latter one drops after one or two days when the female flower is no more receptive. Enclosing in muslin bags after pollination is thus superfluous.

Under the conditions of the tropical lowland climate in Java, several cultivars did not flower at all or only very late. Flowers borne at tall plants necessitate working on ladders which leads to a decrease in number of flowers being pollinated per day. Koch (1934) found that by planting his cultivars at an altitude of at least 3000 feet above sea level, nearly all cultivars produced flowers at an earlier age and at such a height that pollination could be effected much more easily. In this way two native assistants could perform 2500 pollinations in two days.

RESULTS

For the sake of clearness, our results are classified in three groups viz.:

a. Crosses within the species *Manihot utilissima*

b. Crosses between *M. utilissima* and *M. glaziovii*

c. Crosses between *M. utilissima* and *H. saxicola.*

a. The results of different crosses within *M. utilissima* over four years with percentages of success, number of seeds harvested and number of seeds per fruit are given in Table I. Crosses with less than 200 pollinations are excluded from this compilation.

Table I. Results of pollinations between various cultivars of Manihot utilissima.

Year	number of pollinations	number of fruits	% success	number of seeds harvested	mean number of seeds per fruit
1937	2344	356	15	—	—
1939	17689	1706	10	3588	2.1
1940	19565	2823	14.4	3672	1.3
1941	13969	2495	17.8	4307	1.7

The compiled results in Table I give no idea on the differences in success with respect to the different combinations of parents, and the mean number of seeds per fruit. These, however, were fairly large. In Table II the extreme values are given for the different years.

Table II. Extreme values of percentages of success in different years.

	% success		mean number of seeds per fruit	
year	highest	lowest	highest	lowest
1937	17.–	3.–	—	—
1939	20.–	0.3	2.6	1.1
1940	25.9	1.–	1.9	0.4
1941	37.–	1.–	2.6	0.6

From the detailed results per crossing which cannot be given here on account of space, it was clear, however, that crosses with a higher success than 10% were only to be found if one or both parents belonged to a group of four cultivars i.e. F.357, Boger, S(ao) P(edro) P(reto) and Mangi. The first two are hybrids selected at Buitenzorg, whereas S. P. P. and Mangi are imports from Brazil. Most of the crosses were made reciprocally with, on the average, the same degree of success. With the cultivar Mangi, however, most flowers dropped during flowering, which becomes obvious in the crosses where Mangi was used as the female parent. In 1939 the cross S.P.P. x Mangi gave 18% success, the reciprocal cross however only 3%. This phenomenon also occurred in reciprocal crosses when using a hybrid E 17 which had Mangi for one of the parents. Very bad results were obtained with cultivar Singapore which was used as female parent in 1940 and 1941. In combination with six different male partners the success did not exceed 1% with five of them, with F 357, the success was 22.5%, with only 0.4 seed per fruit.

b. Crosses between *M. utilissima* and *M. glaziovii*. Under this heading come also crosses between F_1 hybrids and backcrosses of F_1 hybrids with the cassava parent.

Table III. Results of reciprocal crosses between M. utilissima and M. glaziovii.

Cross	number of pollinations	number of fruits	% success	number of seeds harvested
M. util. x M.glaz	730	42	6.–	50
M. glaz. x M.util.	453	8	2.–	—

Of the cassava parent used crosses involving F 357 cultivar always gave good results. From Table III it is clear that only some success could be obtained when the cassava was used as the female parent.

The hybrids grown from seeds harvested were given H numbers. When intercrossed, these H-hybrids generally gave very unsatisfactory results. Out of 10 combinations totalling 1003 pollinations only 16 seeds were obtained, ten from which were the result of one single combination. Backcrossing of the species hybrids with the cassava parent (F 357) gave much better results.

The results of these backcrosses are compiled in Table IV.

Table IV. Results of backcrosses of F_1 species hybrids with the cassava parent.

year	cross	number of pollinations	number of fruit	% success	number of seeds harvested	mean number of seeds per fruit
1940	F 357 x H 5/9	1115	335	30	449	1.3
	H 5/9 x F 357	1056	87	8	——	——
	F 357 x H 5/2	1105	7	1.1	——	——
	H 3/2 x F 357	1341	182	18	407	2.2
1941	F 357 x H 5/9	1280	49	3.7	59	1.2
	H 5/9 x F 357	620	142	11.–	242	1.7
	H 5/8 x F 357	197	——	—	——	——
	H 5/3 x F 357	89	——	—	——	——
	S.P.P. x H 5/9	1100	162	14.–	375	2.3
	Singapore x H 5/9	600	2	—	5	2.5

From the data in Table IV it is clear that a reasonable amount of success can only be expected when cassava is used as the female parent. The majority of the species hybrids produced very few flowers and only two of the nine hybrids available could be used with some success. Cultivar Singapore again proved to be a bad parent.

Plants grown from the seeds of these backcrosses were a very variable lot from which ultimately only four remained as promising. From these four, 17 proved to be the best one. Combinations of the F_2 hybrids yielded much better results than those of the F_1 hybrids. Whereas in the case of the F_1 hybrids 1000 pollinations produced 16 seeds, four combinations of the F_2 hybrids succeeded in 113 fruits with 155 seeds out of 2398 pollinations.

Backcrossing of these F_2 hybrids with a cassava parent also gave generally much better results than those of the F_1 hybrids. The results of a number of backcrosses are compiled in Table V.

Table V. Results of backcrosses of F_2 species hybrids with different cassava parents.

cross	number of pollinations	number of fruits	% of success	number of seeds harvested	mean number of seeds per fruit
17 x F 357	940	46	5.–	27	0.6
F 357 x 17	1740	180	10.5	225	1.2
17 x 269	150	34	22.5	16	0.5
269 x 17	1120	16	1.4	3	0.2
S.P.P. x 17	1160	257	22.–	562	2.2
Singapore x 17	1200	10	1.–	9	0.9
17 x Bogor	500	51	2.5	7	0.5

From these results it is clear again that the best success may be expected when cassava is used as the female parent. In contrast to the crosses with F_1 hybrids, no combination appeared to be an entire failure.

c. Crosses between *M. utilissima* and *M. saxicola*. Under this heading are backcrosses with the F_1 hybrids and crosses of *M. saxicola* with an F_2 hybrid (17) of a *glaziovii* — cassava cross. A description of *M. saxicola* has been given by Bolhuis (1953). Seeds were obtained from Surinam yielding a number of very uniform plants which at Buitenzorg flowered profusely. Crossing was affected with the cassava cultivar Basiorao, a brasilian import, which flowered simultaneously. The results of these crosses are shown in Table VI.

Table VI. Results of crosses between M. utilissima and M. saxicola.

cross	number of pollinations	number of fruits	% of success	number of seeds	number of seeds per fruit
M. sax. x Bas.	335	125	36.7	76	0.6
Bas. x M. sax	96	47	49 –	80	1.7

Particularly striking is the high percentage of success which is far in excess of the percentages found in crosses within the species *M. utilissima*. It makes it even questionable as to whether *M. saxicola* is sufficiently different from *M. utilissima* to consider it as a separate species, since both crosses have such a high percentage of success. There is, however, a considerable difference in the number of seeds per fruit. The hybrids resulting from these crosses were backcrossed with cultivar F 357 as cassava parent. The results are being compiled in Table VII.

Table VII. Results of backcrosses of sax. — util. hybrids with a cassava parent.

cross cross	number of pollinations	number of fruits	% of success	number of seeds	number of seeds per
(M. sax. x Bas) x F357	2990	1466	49	1070	0.7
(Bas x M. sax.) x F357	2440	275	11.3	251	0.9

In these backcrosses it matters whether *M. sax.* or the *cultivar Basiorao* is used as the female parent in the first cross. The yield in seeds per fruit is however low in both combinations.

Save for these crosses *M. saxicola* was also crossed reciprocally with 17. The results are shown in Table VIII.

Table VIII. Results of reciprocal crosses between M. saxicola and an F_2 hybrid of M. util. and M. glaziovii.

cross	number of pollinations	number of fruits	% of success	number of seeds	number of seeds per fruit
17 x M. sax	633	4	6.5	10	0.25
M. sax. x 17	527	55	10.4	16	0.3

It appears that the making of a triple species hybrid is quite feasible. The data of the reciprocal crosses do not differ very much and the very low number of seeds per fruit in both combinations is remarkable.

DISCUSSION.

When breeding cassava by means of cross pollination the plant breeder generally wants as large a number of plants as possible to be able to select extremes. Being a vegetatively propagated crop plant, the cassava is very heterozygous and heterogenous. In this respect, it is important to know whether a reasonable amount of seeds can be expected from controlled crosses. From the data given in Table II and from experiences with several cultivars, it is clear that in Java this amount of success can only be expected when a relatively small number of cultivars is used as parent clones. Other cultivars generally yielded very poor or no results at all. With the right combinations of parents, a percentage of success can be expected of at least 25%. From Table II it can be seen that in the consecutive years the percentage of success can be increased by the right choice of parents. Large differences are to be expected in the number of seeds per fruit, which, however, may be influenced in a large measure by the weather in the ripening period. Of all the combinations of cultivars, only two had no success at all. Nichols (1947), however, found many sterile combinations. He attributes this to incompatibility, but according to our data, this has still to be proved. In one year, the combination Singapore x Bogor gave no success at all, in another year, this combination yielded very poor results. Nichols conclusions are obviously based on a too low number of pollinations.

Large differences occur also in the number of seeds per fruit. This may be caused by unfavourable weather conditions as was the case in 1940 (see Table 1) when a lot of seed failed to develop in the fruits. At harvest, only sound normally developed seeds were counted. With certain crosses, the average number of seeds per fruit, however, is so low that other causes may be taken into consideration. Both Koch (1934) and Nichols (1947) assume that this may be caused partly by parthenocarpy; cytological and morphological research may lead to a better insight in this matter.

In the Ivory Coast, Meige (1954) found in the cultivar collection of the ORSTOM, different types of sterility; male sterility, female sterility and total sterility. His cytological research was, however, restricted to only one example of male sterility wherein he found that meiosis was normal, and that the pollen grains degenerated before maturing. In the case of total sterility he mentions that parthenocarpy may be present or not. Crosses of partly sterile cultivars with fertile ones, however, were not attempted.

Abraham (1957) made a large number of cassava crosses but he does not mention any percentages of success or number of seeds per fruit. Cours and Fritz (1960) mention that there is no pollen formation at all in certain of their cassava hybrids; the male flowers being sterile. This fact is, however, neither mentioned by any other author nor borne out by the results of the crosses at Buitenzorg where also cassava hybrids were used as the male parent.

The results of crosses with *M. glaziovii* (Ceara rubber) are in accordance with the data given by both Koch (1934) and Nichols (1947). *Koch* (1934) mentions a fair amount of fruit-setting in free pollinated F_1 hybrids, but after some weeks most of the developed fruits dropped off. *Doughty et al.* (1955) report very low seed set with glaz. — cassava hybrids when selfed and also when backcrossed with the cassava parents. Much better seed production, however, was noted when they were intercrossed. These data are not in accordance with the findings at Buitenzorg.

From our experiences at Buitenzorg it can be concluded that the first backcross hybrids can be useful for practical growing.

Abraham (1957) made thousands of pollinations with Ceara rubber as female parent without any success. With cassava as the female parent, however, he got 1% success. This is entirely in accordance with our findings.

Comparison of the results of crosses with *M. saxicola* at Buitenzorg with those of Nichols (1947) in Tanzania is not possible due to the great sensitivity of this species to cassava mosaic. He made only a few crosses and left his F_1 hybrids to pollinate freely among themselves.

Jennings (1959) crossed cassava with *Manihot melanobasis* and found the hybrid to be very fertile but the mean number of seeds recovered per fruit was rather low. Crosses of his F_1 hybrids with *M. glaziovii* gave better results. According to Koch (1934) crosses of cassava with *M. dichotoma* were entirely unsuccessful. Nichols (1947), however, records success in both ways, but his F_1 hybrids proved to be entirely sterile.

CONCLUSIONS.

1. Crosses of cassava cultivars show largely different results. At Buitenzorg

only a few cultivars proved to give fairly good results when used as parents in hybridisation work. When based on the right cultivars a percentage of success of at least 20% may be expected.

2. Some cultivars proved to be very bad parents, in crosses hardly any or no seeds were harvested. In how far this is due to incompatibility has yet to be proved.

3. Cassava can be crossed with several other species of Manihot. The percentage of successful pollinations, however, is generally very low. Moderate good success of these interspecific hybridisations is only to be expected if cassava is used as the female parent.

4. F_1 hybrids between cassava and *M. glaziovii* show a high rate of sterility when intercrossed. Backcrossing of the hybrids with the cassava parent gave fairly good results provided a good cassava cultivar is used which gave also success in cassava crosses

5. Crosses of cassava with *M. saxicola* gave a high percentage of successful pollinations which makes it doubtful whether *M. saxicola* should be considered as a separate species. Backcrossing of the hybrids with a cassava parent gave exceptionally good results when in the original interspecific cross *M. saxicola* is used as the female parent.

6. It is proved by two authors that hybrids containing the "blood" of three species can be obtained.

7. In the majority of crosses the mean number of seeds per fruit was rather small. Further investigation as to the nature of this phenomenon are worthy of recommendation.

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PRELIMINARY WORK ON THE PROBLEM OF CLASSIFYING MANIOC VARIETIES

— *by* —

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Classification of manioc has generally been limited to a distinction between "sweet" and "bitter" varieties. This common method of classification is based entirely on the taste of the roots (cortex or edible part) which in turn depends largely on the hydrocyanic acid (HCN) content. However, since the HCN content of a given plant fluctuates not only with the physiological stage of the plant but also with the region where it is cultivated, the differentiation between "sweet" and "bitter" varieties does not provide a sound basis for classifying manioc.

The problem of classifying the varieties and cultivars of manioc grown in the tropical and sub-tropical areas of Latin America is complicated by the multiple names given to the same variety and/or cultivar in different countries. According to Barnes (1954) the large number of manioc varieties found in northeastern South America suggests that this area is its original center of domestication while Rogers (1963) postulates two major species centers, one in Mexico and Central America, the other in northeastern Brazil as far as Matto Grosso and including parts of Paraguay. Thus, it appears that the varieties and cultivars of manioc found in Latin America today have been introduced into the various countries from only one or two centers of origin and that in the process of diffusion they acquired different names as they spread from one region to another.

Rogers (1963) points to still another difficulty when he observes that there is some evidence that certain cultivars have hybridized with locally occurring natives species in both geographical centers to form a number of complexes.

Previous studies of manioc by Graner (1942) and Rogers (1963) provide the basis for the classification of manioc presented in this paper. Graner found that the form of the leaf and the coloration of the phelloderm of the root segregate independently and that the form of the leaf is largely dependent on environmental conditions. Working with vegetative material from Jamaica, Costa Rica, Nicaragua, Brazil, Bolivia and Peru, Rogers noted the existence of two stable combinations of vegetative characteristics which could serve as the basis of a major classification of the species.

The present study was conducted on a collection of varieties and cultivars maintained by the Instituto Nacional de Investigaciones Agricolas (INIA) in the Centro de Investigaciones Agricolas del Sudeste (CIASE) which is located at the Campo Cotoxtla, a sub-tropical coastal region near Veracruz, Mexico. The plants of this collection were introduced into Mexico from Brazil, Costa Rica and Colombia (Contreras, 1964). Only one previous study of this collection has been

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published. On the basis of characteristics such as resistance to strong winds and the shape, size and uniformity of the roots, Contreras (1964) selected and described the eight varieties of this collection which appeared to be most promising.

The work presented in this paper represents a preliminary attempt to classify the varieties and cultivars of the above mentioned collection on the basis of certain morphological characteristics. In addition, the HCN concentration in the roots was determined in order to see if any relationship exists between the morphological characteristics used in this classification and the HCN content of the roots. The adaptability and productivity of the plants were also observed for the purpose of selecting the best varieties for distribution in the tropical regions of Latin America.

MATERIAL AND METHODS

On February 10, 1966, eleven cuttings of approximately 40 cm each were taken from each variety included in the Campo Cotaxtla observation plots. These cuttings were planted with about 1/3 of their total length under ground and with an inclination of approximately 45°. A distance of 1.50 m. was left between rows and the cuttings were placed 1.00 m. apart. From planting until harvest all the plants were submitted to the same cultural practices.

Ten months after the cuttings were planted, 5 plants of each variety were harvested (December 22-23, 1966) and one month later (January 18, 1967) the remaining 6 plants were harvested. Two harvests were made in order to observe what effect the difference of one month might have on production.

The same procedure was followed in both harvests. When the roots were taken out of the ground, the relative degree of difficulty encountered in extracting them was observed. Immediately after extraction, the colour (dark brown or light pinkish tan) and texture (rought or smooth) of the epidermis as well as the shape of the roots (cylindrical, conical or irregular were recorded). When the roots were seperated from the stem, the relative difficulty encountered in separating these two plants parts and the nature of the point of attachment between them was noted. The roots of each variety were then classified into three commercial sizes:

- No. 1 – large roots (for possible industrial use),
- No. 2 – medium roots (for human consumprion), and
- No. 3 – small roots (for use as animal feed).

The number of roots and the weight of the roots included in each of these crops were also recorded.

At the second harvest, 5 kilo compound samples of the roots of the six plants of each variety harvested were sent for chemical analysis. The plant samples were analyzed by the Departmento de Bioquimica of the Centro Nacional de Investigaciones Pecuarias, Palo Alto, Mexico, D. F.

The cyanogenetic glucosides were determined as hydrocyanic or prusic acid by the acid titration method (7) and the % of dry weight, nitrogen-free extract, ether extract, mineral matter, crude protein, crude fibre, Ca, P and K were analyzed. However, the results of the bromatological analysis are not reported at this time.

RESULTS AND DISCUSSION

The source given for each variety in Table I does not refer to the place of origin of the variety but rather to the location of the collection from which the vegetative material was obtained to form the manioc collection of Campo Cotaxtla. The 31 varieties harvested were divided into groups on the basis of skin color and texture. The results of this classification confirm Roger's observation of two stable combinations of morphological characteristics since it was found that the roots that had a dark brown colour had a rough texture while the light tan or pinkish tan roots were invariably smooth. Twenty-one varieties were found to have a dark brown skin and a rough texture, 9 varieties were light tan in color with a smooth skin and 1 variety, Big Yard Marlie Hill, was pinkish tan with a smooth skin. It was also noted that within the group classified as dark brown/rough there was considerable variation in the shade of brown. However, the dark brown roots were clearly distinguishable from the light tan or pinkish tan roots.

In addition to skin color and texture, certain other characteristics of the roots were observed which might be investigated as a possible basis for refinement of the two major divisions already noted by Rogers (1963). The roots classified as dark brown/rough showed some variation in relation to the number and size of the "lenticelia", the color found immediately under the epidermis and the tendency to peel (In this study "flaking" or the presence of small scale-like pieces of skin was considered as a condition inherent to "rough" skin and therefore was not used as a separate characteristic, while "peeling" was distinguished from "flaking" in that the skin actually came off the roots. However, this could have been due to a condition of immaturity).

Most of the dark brown/rough varieties had a light yellowish color under the epidermis. However, the variety Elmo Stick had a purple color while Sin nombre H-56 and Criolla had a pinkish color under the skin. Several other varieties, such as Yucateca, showed signs of peeling. Although the tendency towards peeling may be largely governed by heredity in that it is related to the thickness of the epidermis, the texture of the soil and the method of harvesting may also be important factors.

The roots classified as light tan or pinkish tan and smooth showed less variation in relation to the characteristics mentioned above and less variation in the color of the epidermis. However, it must be noted that about twice as many dark brown/rough varieties as light or pinkish tan/smooth varieties were studied and this may account in part for the smaller degree of variation found among the light or pinkish tan/smooth varieties.

No relation was found between skin color and texture and production since plants of high production as well as plants of medium and low production were found in both major groups (dark brown/rough and light or pinkish tan/smooth). In Table 2 the production of the varieties studied is presented in terms of the average number of roots per plant, the average yield (kilos) per plant and in the estimated value of tons per hectare. Of the 31 varieties, Eye Wather, EPC No. 3 tipo dulce, Sin nombre H-56 and Valluna were found to have either very low production or low quality roots.

Regarding production, it should be mentioned that high yield alone does not constitute a superior variety. The HCN content and size of the roots as well as certain factors that facilitate or obstruct harvesting such as the ease of extraction, which is dependent largely on the distribution of the radical system, and the ease with which the root can be severed from the stock, are also important factors. Among the varieties studied, Yellow Saunders, a variety of average yield, was found to be very difficult to harvest because its roots go deep into the soil.

Separation of manioc varieties into commercial grades according to the size of the root (Table 3) provides a basis for selecting the best varieties for specific uses. However, it should be pointed out that the results of the grading presented in Table 3 are valid only for plants harvested after 10 months of growth since the size of the root attained within a given amount of time depends to some extent on the precocity of the variety.

The following 10 varieties, which are described in some detail, were considered outstanding because they presented a better combination of desirable characteristics than the other varieties studied. The varieties that produced the highest yields are included in this list. However, HCN content was not taken into consideration in this appraisal.

C59 — 6 Light tan/smooth. The roots, which are short and thick, bulge at the point of attachment to the stock and are difficult to sever. This variety produced a good number of roots per plant and had the highest yield (58.9 t/ha) of all the varieties studied.

Elmo Stick Dark brown/rough. A purple color was noted below the epidermis. The roots are long and slender and irregular in shape. The plant had a large number of roots and produced a high yield (51.8 t/ha). 60.9% of the roots were of No. 1 size.

Big Yard Marlie Hill Light tan/smooth. The conical-shaped roots of this variety are difficult to sever because they are thick at the point of attachment to the stock. The roots have a pinkish color under the skin and purple strips on the epidermis. This variety produced a high yield (45.6 t/ha) and had a large number of roots per plant. 74.8% of the roots were of No. 1 size.

C59 — 9 Light tan/smooth. The roots are thick at the point of attachment to the stock. This variety yielded an average of 39.8 t/ha and produced good size roots of No. 2. grade, 74.3% of the roots were of No. 1 size.

Yucateca Dark brown/rough. The roots, which are long, thick and conical-shaped, are easily severed from the stock. The skin of this variety peeled considerably when the roots were harvested; 75.2% of the roots were of No. 1 size and the average yield was 35.5 t/ha.

White Cuban Light tan/smooth. This variety produces a large number of irregular-shaped roots per plant. In percent of the total yield, the proportion of No. 1 and No. 2 size roots was very similar. The yield of this variety was 34.4 t/ha.

Criolla Dark brown/rough. This variety produces many good size roots per plant (75.7% of No. 1 size) that are cylindrical in shape and easily severed from the stock. The roots have a pinkish color below the epidermis. The average yield was found to be 34.3 t/ha.

Guaxupe — Dark brown/rough. The conical-shaped roots of this variety are long, thick and straight. They are easily separated from the stock and of an excellent external appearance in general. The production was 31.9 t/ha.

Cubana — Dark brown/rough. The roots are irregular in shape and easily separated from the stock; 55.3% of the roots were No. 1 size and the No. 2 size roots had an especially good appearance. This variety yielded 29.4 t/ha.

Smalling — Dark brown/rough. The cylindrical-shaped roots are thick at the point of attachment to the stock and difficult to sever. Although its total production was not high (an average of 22.6 t/ha), this variety produced the highest percentage of roots of No. 1 size (78.1%).

Manioc roots with an HCN content of less than 5 mg. per 100 g of fresh weight are considered "sweet" while roots with an HCN concentration between 5 and 10 mg. per 100 g are classified as being of "medium toxicity" (Casseres, 1966). According to Jones (1959), roots with an HCN content greater than 10 mg./100 g of fresh weight are too toxic for consumption and suitable only for industrial use.

The results of the chemical analysis made of 30 manioc varieties in this study (Table 4) show that none of the varieties of the Campo Cotaxtla collection produce "sweet" roots since the lowest concentration of HCN found in the cortex was 5.8 mg./100 g of fresh weight.

Of the 30 varieties analyzed, 10 had an HCN content between 5 and 10 mg./100 g. Three of these ten varieties, Guaxupé, Cubana and Smalling, were among those singled out as superior varieties. These three varieties, all highly productive, had an HCN content of 8.6, 9.4 and 6.5 mg./100 g of fresh weight respectively.

Sin nombre H-56, the variety that had the lowest concentration of HCN in the cortex (5.8 mg./100 g) had a very low yield (1.9 t/ha) while Zopilota, the variety that had the second lowest content of HCN in the cortex (6.0 mg./100 g) produced a medium yield. Thus, varieties of high (Guaxupé, Cubana and Smalling), medium (Zopilota) and low (Sin nombre H-56) production were included among those that had an HCN concentration of "medium toxicity". It is also interesting to note that all 10 varieties of "medium toxicity" belonged to the dark brown/rough group while 4 of the 9 varieties that had a very high content of HCN (more than 18 mg./100 g) were of the light tan/smooth group. Four of the nine varieties that had a very high HCN concentration were also among those selected as the best varieties of the Campo Cotaxtla collection.

The results of this study agree with the observation of Jones (1959) that there is no good correlation between morphological characteristics and hydrocyanic acid content.

Six of the varieties of the Campo Cotaxtla collection described by Contreras

(1964) were also included in this study. Contreras did not analyze the HCN content of the roots, but he did classify them as ranging between "sweet" and "bitter" on the basis of taste. A comparison of his classification with the results of the analysis of the HCN content made in this study shows that there was discrepancy between the two ratings in many cases. For example, Contreras considered the variety Sra. está en la mesa, whose HCN content was found to be 21.9 mg./100 g, a "sweet" variety, while a variety he described as somewhat "bitter" (Guaxupé) was found to have only 8.6 mg./100 g of fresh weight. These differences may be explained at least in part by the fact that the HCN content may vary in different samples of the same variety and even in different roots of the same plant (Casseres, 1966).

SUMMARY AND CONCLUSIONS

Working with vegetative material from the manioc collection maintained at Campo Cotaxtla near Veracruz, Mexico, an exploratory classification was made on the basis of certain morphological characteristics, the HCN content of the roots was analyzed and a number of varieties selected as outstanding in this collection were described.

The following conclusions may be drawn from this preliminary study:

1. The epidermis of the mature roots of all 31 varieties included in the Campo Cotaxatla collection were either dark brown with a rough texture or light tan with a smooth texture.

2. In addition to skin color and texture which served as the basis for classifying the manioc varieties into two groups, a group of secondary morphological characteristics that might serve as a basis for refining the classification was observed. These secondary characteristics, which will be studied in detail in the future, included the size and number of the "lenticella", the pigmentation found immediately under the epidermis, and the tendency to peel.

3. Varieties of high, medium and low production were found in both major groups of manioc (dark brown/rough and light or pinkish tan/smooth).

4. On the basis of HCN content, none of the varieties included in the Campo Cotaxtla collection can be considered "sweet". Of the 30 varieties studied 10 had an HCN content between 5 and 10 mg./100 g of fresh weight while the other 20 varieties had more than 10 mg. of HCN per 100 g of fresh weight.

5. No apparent correlation was found between morphological characteristics and HCN content.

Table 1. Morphological characteristics of the roots.

Accession number		Name (x)	Source	Epidermis of mature roots	
				Color	Texture
2001	SG 467	C59-- 6	Brazil	light tan	smooth
2	SG 435	C59— 9	Brazil	light tan	smooth
3	SG 445	C59-- 10	Brazil	light tan	smooth
4	SG 596	C59—12	Brazil	dark brown	rough
5	SG 582	C59--13	Brazil	dark brown	rough
6	2070	Sra. está en la mesa	Costa Rica	dark brown	rough
7	2783	Cubana	Costa Rica	dark brown	rough
8	2888	Bayuna No. 3, tipo dulce	Costa Rica	light tan	smooth
9	3056	Bullet tree	Costa Rica	dark brown	rough
10	3028	Ebno Stick	Costa Rica	dark brown	rough
11	3036	Yellow Saunders	Costa Rica	dark brown	rough
12	3040	Eye Wather	Costa Rica	dark brown	rough
13	3049	Smalling	Costa Rica	dark brown	rough
14	3052	White Stick	Costa Rica	light tan	smooth
15	3060	Bunch of Keys	Costa Rica	dark brown	rough
16	2886	EPC No. 3, tipo dulce	Costa Rica	dark brown	rough
17	3044	White Margaret	Costa Rica	light tan	smooth
18	3047	Big Yard, Mallic Hill	Costa Rica	pinkish tan	smooth
19	3050	White Cuban	Costa Rica	light tan	smooth
20		Crema	Costa Rica	light tan	smooth
21		Siete meses	Costa Rica	dark brown	rough
22		Camota	Costa Rica	dark brown	rough
23		Zopilota	Costa Rica	dark brown	rough
24	1144	Sin nombre, H-56	Costa Rica	dark brown	rough
25	1146	Valluna	Colombia	dark brown	rough
26	1148	EPC No. 3	Colombia	light tan	smooth
27	1150	Sin nombre, H-56-1	Colombia	dark brown	rough
28	192	Itu	Colombia	dark brown	rough
29	454	Guaxupe	Colombia	dark brown	rough
30		Yucateca	Mexico	dark brown	rough
31		Criolla	Mexico	dark brown	rough

(x) The numbers included with the names are those given to the varieties in the collections from which they were obtained.

Table 2. Root production of 31 varieties of maniac harvested 10 and 11 months after planting. Average number of roots per plant, average yield per plant and estimated value of tons per hectare.

Variety	Harvest 1			Harvest 2		
	roots /plant	k/plant	t/ha	roots /plant	k/plant	t/ha
C59— 6	16.4	10.62	70.8	13.2	7.37	4.91
C59— 9	9.6	6.70	44.7	11.5	5.37	35.8
C59—10	7.6	3.06	20.4	7.2	3.47	23.1
C59—12	9.2	1.24	8.3	6.2	1.57	10.4
C59—13	5.6	1.20	7.9	5.7	2.23	14.9
Sra. está en la mesa	10.4	2.96	19.7	10.5	4.67	31.1
Cubana	10.8	4.56	30.4	11.2	4.28	28.6
Bayuna No. 3, tipo dulce	9.6	3.28	21.9	6.0	2.13	14.2
Bullet tree	7.8	2.42	16.1	2.8	.97	6.4
Blue Stick	11.8	5.64	37.6	16.7	9.55	63.7
Yellow Saunders	10.6	3.90	25.9	7.7	3.70	24.7
Eye Wather	3.8	.90	5.9	5.8	1.95	12.9
Smalling	8.8	3.92	26.1	6.5	2.96	19.7
White Stick	6.6	1.04	6.9	4.3	1.01	6.7
Bunch of Keys	5.8	.60	3.9	4.7	.47	3.2
EPC No. 1, tipo dulce	—	—	—	2.0	.13	.9
White Margaret	10.0	3.34	22.3	3.3	.84	5.6
Big Yard, Marble Hill	16.6	8.96	59.7	13.2	5.08	33.9
White Cuban	14.0	3.50	23.3	21.3	6.55	43.7
Crema	12.4	2.16	14.4	9.0	2.40	15.9
Siete meses	5.2	52	3.5	7.3	2.49	16.6
Camota	3.2	.58	3.9	2.2	.49	3.3
Zopilota	6.6	1.14	7.6	8.0	1.58	10.6
Sin numbre, H-56	4.0	.20	1.3	4.0	.37	2.5
Valluna	1.8	46	3.1	—	—	—
EPC No. 3	3.8	.60	3.9	3.3	.50	3.3
Sin nombre, H-56-1	3.2	.66	4.4	3.7	.97	6.4
Ito	6.6	1.20	7.9	8.7	4.22	28.2
Guaxupe	6.8	3.40	22.7	8.0	5.96	39.7
Yucateca	10.6	4.20	27.9	10.2	6.27	41.8
Criolla	12.4	5.84	38.9	10.7	4.57	30.5

Table 3. Classification of the manioc production into commercial grades expressed as percent of the total yield from the 1st. harvest.

Variety	COMMERCIAL GRADES IN PERCENT No. 1 grade	No. 2 grade	No. 3 grade
C59— 6	63.2%	29.2%	7.5%
C59— 9	74.3	17.6	8.1
C59—10	56.9	22.2	20.9
C59—12	35.5	33.9	30.6
C59—13	31.7	26.7	41.7
Sra. está en la mesa	51.4	33.1	15.5
Cubana	55.3	24.6	20.2
Bayrona No. 3, tipo dulce	54.3	29.9	15.9
Bullet tree	52.1	33.9	14.0
Elmo Stick	60.9	25.9	13.1
Yellow Saunders	68.2	23.1	8.7
Eye Walher	66.7	15.6	17.8
Smalling	78.1	18.9	3.1
White Stick	42.3	32.7	25.0
Bunch of Keys	33.3	40.0	26.7
EPC No. 3, tipo dulce	—	—	—
White Margaret	52.7	22.8	24.5
Big Yard Marlie Hill	74.8	18.3	6.9
White Cuban	38.9	37.7	23.4
Crema	42.6	37.9	19.4
Siete meses	—	46.2	53.8
Camota	20.7	41.4	37.9
Zopilota	38.6	26.3	35.1
Sin nombre, H-56	—	—	100.0
Valluna	—	56.5	43.5
EPC No. 3	43.3	20.0	36.7
Sin nombre, H-56-1	48.5	36.4	15.2
Itu	18.3	41.7	40.0
Guaxupé	73.5	20.6	5.9
Yucateca	75.2	19.0	5.7
Criolla	75.7	18.1	6.2

Table 4. Concentration of hydrocyanic acid (HCN) found in the roots of 11 month old manioc plants.

Variety	mg. HCN/100 g phelloderm	cortex	fresh weight total*
C59— 6	19.0	12.6	16.1
C59— 9	49.9	30.0	34.2
C59—10	49.0	21.6	14.2
C59—12	36.2	12.7	11.5
C59—13	69.6	29.8	34.5
Sra. está en la mesa	23.6	21.9	17.8
Cubana	20.7	9.4	8.5
Bayuno No. 3, tipo dulce	51.1	24.7	18.4
Bullet tree	5.0	8.2	11.2
Elmo Stick	27.4	22.0	33.2
Yellow Saunders	64.0	12.9	15.8
Eye Wather	5.7	12.1	13.0
Smalling	2.3	6.5	9.9
White Stick	9.2	12.7	18.4
Bunch of Keys	10.5	9.7	11.4
EPC No. 3, tipo dulce	18.6	7.4	2.3
White Margaret	9.4	10.3	16.3
Big Yard, Marlie Hill	25.2	11.5	15.4
White Cuban	55.0	18.6	22.7
Crema	24.3	12.1	8.7
Siete meses	15.4	20.3	19.5
Camota	8.3	9.3	10.3
Zopilota	2.3	6.0	3.9
Sin nombre, H-56	15.4	5.8	6.5
EPC No. 3	11.2	11.4	16.7
Sin nombre, H-56-1	6.3	12.0	12.4
Itu	35.3	7.7	9.1
Guaxupe	50.8	8.6	10.9
Yucateca	26.4	19.2	20.3
Criolla	18.6	10.7	11.9
Average	25.5	13.9	15.2

*whole root

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RECENT TRENDS IN CASSAVA BREEDING IN INDIA.

—*by*—

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Cassava (*Manihot esculenta Crantz.*) is rapidly emerging as a crop of considerable importance in India. More than half a million acres are now under its cultivation in Kerala state alone which accounts for about 80% of the total acreage of this crop in India. Its capacity for producing large amounts of food calories per acre, ability to adapt itself to erratic climatic conditions, resistance to locusts and several pests and diseases, easy culture, low labour requirements, low cost of production, etc. are some of its unique features which further encourage the spread of its culture to several other regions of the country. Besides, being an important item of food for a large proportion of the population in Kerala, it provides cheap, nutritive feed for livestock as well. Its tuber has innumerable industrial uses also, particularly for starch extraction (Magoon and Appan, 1966 a and b).

Though cassava has been under cultivation in India for a long time, improvement work on this crop has lagged behind. The field of activity concerning cassava breeding is thus only of recent origin and therefore, many fundamental as well as applied problems require yet to be grasped. A scheme of research on cassava was started in early years at Travancore University, Trivandrum, and the work of the scheme was greatly enlarged under the scheme of research on the improvement of cassava jointly financed by the Indian Council of Agricultural Research and the Government of Travancore-Cochin (now Kerala). The results obtained on the various aspects of the cultivation of cassava in India during 1940-57 are summarized by Koshy (1947) and Abraham (1957).

Considering the importance of the various tuber crops in the Agricultural economy of the country, the Government of India (Indian Council of Agricultural Research) recently established the Central Tuber Crops Research Institute at Trivandrum for the intensification of research on the improvement of various tuber crops, other than potato. The main function of the Institute is to undertake fundamental as well as applied work on all aspects of tuber crop improvement; some of the objectives are to evolve and formulate practical measures for increasing production of tuber crops by (i) breeding of high yielding, better quality, disease and pest resistant varieties, (ii) determination of optimum standards of culture, manuring and storage, (iii) survey, investigation and control of major diseases and pests which take a heavy toll of these crops in field and of tubers in storage, (iv) production, maintenance, multiplication and distribution of disease free, pure propagating material of improved varieties and (v) gathering fundamental data on the botany and cyto-genetics of the various tuber crops as also on certain agronomical, chemical, physiological, entomological, mycological and pathological aspects of these crops. In this article, I shall try to outline briefly some of the main items of research work at present underway on the improvement of cassava at this Institute.

A WEALTH OF MATERIAL

Genetic variability is the essence of any plant breeding programme. A germ plasm bank of the different tuber crops including wild relatives and allied material from within and outside the country has been built up.

For instance, in cassava, 960 so-called "types" have been collected from various places in India; some have also been obtained from various countries. This entire collection is being carefully screened for several economic characteristics for purposeful utilization of this genetic variability. Studies so far made at the Institute in this regard show that there is considerable variation among the germ plasm collection with regard to physiological characters as yield of tubers, field resistance to diseases and pests, response to various levels of soil fertility, maturity period, storage behaviour of tubers, cooking quality, drought resistance and biochemical characters such as prussic acid content of tubers, starch content of tubers, etc.

Many of the cassava "types" under cultivation in Kerala and other states in India are either chance seedlings or bud mutations, selected for desirable characteristics and maintained by vegetative propagation. Varieties best suited to the requirements imposed by the local conditions are generally adopted and popularised in the various cassava growing tracts. The majority of the types have native names which generally indicate one of the striking features of the plant, like for instance, "Arakomban" meaning the tubers white and long similar to an elephant's tusk. The maturity period of the different indigenous varieties varies from 7-12 months. Varieties with lesser toxicity are generally preferred in many areas but when the crop is grown for processing the tubers into starch flour, chips, manioc meal, livestock feed, etc., and not for immediate human consumption, high yielding varieties are preferred, irrespective of bitterness.

THE NEED FOR A CLASSIFICATION

There have been divergent views regarding the classification to be adopted in this genus and to the taxonomic status to be given to the various entities, as also concerning the evolutionary relationship between them. In many instances, the delimitations of inter-, intra- and infra-specific categories in this variable group of plants lack the sharpness that a study of evolutionary inter-relationships would require (see Rogers, 1965; Bolhuis, 1953; Croizat, 1942; Jennings, 1959; Jones, 1959 and others). Cassava was classified by earlier botanists into bitter and sweet types, according to the taste of the tuberous root. Some workers assign the bitter types (those cultivars that have a high concentration of cyanogenetic glucoside in the root) to *M. utilissima* Pohl, and others refer to the sweet types (with low concentration or no cyanogenetic glucoside in the root) to a distant species, variously designated as *M. palmata*, *M. dulcis* or *M. aipi*. However, this differentiation has not commonly been accepted from a taxonomic standpoint, as the taste of the tuber is not regarded as a character of specific or varietal importance. Rogers (1965) has rightly emphasised the need to classify all the cultivars as one highly variable species, using the name *Manihot esculenta*, the earliest valid name proposed by Crantz (1766). Within the species several types or races, based on several morphological criteria, are recognized. Several wild forms or species are also recognized in the genus (see Rogers, 1965; Jennings, 1959 and others).

Attempts have been made from time to time in different parts of the world at systematically classifying the large number of so-called types or races or forms of *M. esculenta* available to the workers of the particular region on morphological criteria, geographic distribution and ecological preferences, etc. However, it must be admitted that while some notable taxonomic work has been done in this direction (see Rogers, 1957, 62, 63 and 65, Croizat, 1942, Koshy, 1947 and others) which has resulted in the recognition of species, sub-species, types, lower entities, etc., genetic and cytogenetic evidence which can additionally help in developing a more natural classification based on ancestral relationships is still far from adequate. The work in this direction has recently been taken up at this Institute. The various available types were classified to begin with on distinct vegetative characters such as colour of mature stem, young stem, emerging shoot, base of the petiole, base of the stipule, veins on the ventral surface of the leaves and growth habit, including nature of branching, etc., floral characters such as colour of perianth and disc, and tuber characters such as shape and surface texture of the tubers, colour of skin, rind and flesh, and time taken for cooking, etc. Workable keys have been prepared for identifying the distinct types on the basis of the above characters. Nine hundred and sixty cultivated so called types collected were critically studied in the light of the above system and, it has been found that a good number of indigenous types are similar if not identical, though known by different names in different localities. Out of this collection studied, only about 100 distinct types have so far been isolated. Nevertheless, the extreme difficulty at times of identifying the clone by its observable morphological features and the changeableness of the clones when placed in different environmental conditions combine to make the system not fully satisfactory. Hence, a combined study of morphological, cytological, genetical and other aspects has been undertaken, in order to develop a more acceptable classification. It is felt that "inclusive herbarium" of the type envisaged for maize by Anderson (1951) and *Sorghum* by Magoon and his associates (Magoon, 1966; Magoon and Shambulingappa, 1962 a and b, 63; Magoon *et al*, 1961 & 64; Sadasivaiah and Magoon, 1965 and others) would be very useful in cassava as well. In these studies, besides morphological characteristics, cytological features, especially the data on the morphology of pachytene chromosomes are also included.

A comparison of the chromosome morphology and the process of meiosis in different taxa is one of the ways of arriving at an estimate of the relationship between different taxonomic entities, especially at the species and lower levels. A similar study in cassava would be most appropriate since little headway can be made in the taxonomic treatment by studies based on chromosome numbers alone, as all the cultivated indigenous types thus far studied at the Institute possess 2n = 36 chromosomes. Thus, the evaluation of comparative karyomorphological differences amongst the various types is desirable. This would necessitate the precise identification of each of the 18 chromosomes of the haploid set, preferably accompanied by the location of some marker genes on each of them. Such studies have recently been initiated.

Unfortunately, cytological studies in this group of plants, perhaps due to the lack of suitable techniques, were till recently largely confined to the determination of chromosome numbers. Critical analysis of the synaptic behaviour of chromosomes in the species or types, etc. as well as in hybrids had been greatly neglected. Chromosome homology is believed to be the property of the chromosome segments which are units of evolutionary changes. Thus, the analysis of the nature of pairing at pachytene stage in inter-specific or inter-racial hybrids or even in a population of a species provides the best chance of scanning the different regions of the bivalents for structural hybridity thereby revealing, cryptic duplications, inversions, differential segments, deletions, non-pairing segments, etc. undetectable at diakinesis and later stages. In fact, the nature of chromosome pairing particularly at the mid-pachytene stage in the hybrids studied so far has been indeed very useful in providing considerable information bearing on the presence or absence of structural changes between the chromosomes of the types. Besides, normal meiosis in some hybrids, irregularities such as the presence of minute, though cytologically detachable, structural differences like small duplications and deletions, loose pairing, differential segments, terminal and interstitial non-pairing regions, etc. have also been found in certain other hybrids. The role played by some of them in serving to restrict the homology between chromosome complements of these different taxa thereby providing an effective mechanism of genetic differentiation are being evaluated. The classification based on morphological criteria is thus supplemented by the cytological and fertility data and the various types are being lumped and re-arranged accordingly. Genetical studies have also been taken up.

A knowledge of the internal mechanisms responsible for differentiation in this group of plants is of great importance from the practical point of view also, because the breeder, has to resort to crossing, if he is to successfully incorporate some desirable genes into the commercial, cultivated forms. The procedure of incorporating the desirable genes from the related flora particularly the wild ones into the commercial forms faces various handicaps such as hybrid sterility and viability. But even when the hybrids are not sterile and are fully viable, it cannot be at once assumed that a free interchange of genes between the two species is to be expected. That this has not been realized in practice is only too well known. Stebbins, *et al* (1946) considering the limitations for such a free interchange of genes have taken recourse to the estimation of recombination index as an aid to the breeder. If the recombination index calculated on the basis of pairing and chiasma frequency at MI could be put to such use, data on pairing at pachytene stage could be all the more useful. From such a study, it should be be possible to suggest to the breeder the cross combination he should concentrate his selection upon, so that he could direct his efforts only to beneficial cross combinations among these forms.

STUDIES ON THE MECHANISM OF POLLEN ABORTION AND PROBLEMS OF NON-FLOWERING IN CASSAVA

A good number of cassava types now in cultivation rarely flower and some of them have never been known to flower. Sterility is common in crops like cassava and sweet potato which have been propagated by vegetative means for thousands of years. As a result of screening of the large number of cassava types, a varying degree of male sterility has been recorded and 35 types have been found to be completely male sterile. A comparative study of flower, microsporogenesis and development of male gametophyte in a few male fertile lines and some male sterile lines was carried out and based on extensive embryological data, the mechanism of pollen abortion in these male sterile lines has been determined. It has been found that in some male, sterile lines, degeneration of individual microspores is probably due to the failure of the separation of microspores from the tetrad which leads to the formation of empty anthers. However, in certain other male sterile lines, the pollen abortion appears to be due to the persistent nature, abnormal behaviour and development of the tapetum (Jos *et al*, 1966 and Magoon, Jose & Vasudevan, 1967). Based on cytological data, it has been suggested that meiotic abnormality is not the cause of pollen degeneration in the material studied. Attempts to study the genetics and breeding behaviour of all these male sterile lines are underway.

Attempts are also underway to study the physiology of flowering. It is now well known that environmental factors including temperature and light, growth regulators and the availability of certain metallic ions play an important role in the expression of the genes responsible for flowering (Searle, 1965). Suitable experiments have been laid out to determine the low temperature requirements and photoperiodic studies in relation to flowering in cassava. Besides, use of gibberellins (GA 3 in varying concentrations) to induce flowering in non-flowering cassava types are also being tried since the Gibberellins can replace long-day and cold treatment requirements in several plants to bring them to flowering (Lang, 1965). On the whole, it is aimed at (a) Synchronization of flowering in varieties to be crossed, (b) making non-flowering and shy flowering varieties to bloom for hybridization and (c) faciliating, if possible, crossing at any time of the year.

PRODUCTION BREEDING

Cassava yields in several parts of India are much lower than those reported from cassava producing areas in countries like Brazil, Madagascar, Java, Malaya, etc. The average yield in India is about 5 tons per acre. In India cassava has been till recently, predominantly a subsistence crop grown under sub-optimal conditions of nutrition and inferior agronomic practices by cultivators mostly in small holdings for domestic and local consumption. It is obvious that an increase in productivity can only result from the application of science and technology. In this process, improved varieties with a built-in potential for responding abundantly to such practices can obviously play a very important role as catalysts. Using better strains under intensive cultivation, high yields ranging from 20 tons to 30 tons per acre have also been reported (see Abraham, 1957 and 1956 and Magoon and Appan, 1966 a & d). Similarly, high yields of cassava have also been obtained by several progressive cultivators in Kerala.

Since cassava is nowadays emerging as a crop of considerable economic importance in India, due to its increasing utility as subsidiary food, industrial raw material and livestock feed (see Magoon and Appan, 1966 b & c) production breeding in this crop consequently must be placed on an urgent footing. Stabilizing the yields at higher and higher levels will now have to be the major problem. Greater attention will have now to be paid in developing early maturing and drought resistant varieties. In recent years, plant type has become an important breeding objective, as the importance of plant habit in the optimum utilization of solar energy has come to be well realized. The results of the preliminary manurial trials conducted at the Institute with a few indigenous commercial varieties, suggest that these do not have the capacity to respond in the optimum fashion to higher dozes of fertilizers. It is obvious, therefore, that breeding for high fertility conditions will have to be a prerequisite if any substantial improvement in the yield of cassava is to be expected within a short period. This line of work forms an important objective of the breeding programme at the Institute. In fact, some of the new selections and hybrids recently developed involving superior exotic material have been found to be particularly promising and they respond well to intensive manuring.

Breeding for the genetic improvement of yield, therefore, requires a well-balanced approach and judicious application of specialized techniques and procedures based on a clear understanding of the principles of genetics and of organic evolution. Along with breeding for yield *per se* in cassava, we have necessarily to build up genetic insurance against the virus disease, "Cassava mosaic," which has assumed serious proportions of late and reduces the yield considerably. In other words, production as well as resistance breeding, the two facets of breeding which are not mutually exclusive, (Joshi, 1963) must go hand in hand. It is only through the use of such improved varieties coupled with good, cultural practices, that cassava production can have any future in India. Consequently, varietal amelioration has received considerable attention in recent years (Abraham, 1957). The approaches to cassava breeding work at the Institute involved the use of familiar tools of introduction and assay, selection, hybridization, genome approach, mutation, etc. The main aim being to develop better varieties having desirable characters by exercising selections in indigenous as well as exotic varieties and in progenies obtained from hybridization between suitable varieties or between these varieties and their closely related wild plants. The work has been planned with specific objectives bearing in mind the requirements of farmer, consumer and industry. The cassava breeding programme is further being supported by a well organized programme of research in cognate fields such as Agronomy, Soil Science, Physiology, Biochemistry, Genetics, Cytology, Pathology and Entomology. Several experiments along these lines are underway but due to lack of space will not be referred here. However, some of the promising selections and hybrids recently developed at the Institute are worthy of special mention.

SELECTION

Considerable amount of diversity still exists in this crop in India. It is felt that vigorous selection work in natural populations, if carried out judiciously, could offer a good scope for immediate improvement of the local materials. In addition, it will also help elimination of degenerated virus infiltrated stocks and unproductive plants. A programme of selection from existing types as well as systematic testing of the available exotic material is therefore, actively under way.

Two introductions (M4, M6) from Malaya (Abraham, 1956) have been found to be high yielding. The Institute obtained seed material from several countries and the chief characteristics of some of the promising selections and hybrids developed involving certain exotic material are described at length by Magoon and Appan (1966 c). For instance, two seedling selections (Accn. Nos. CTCRI-2371 and 1310) made after rigorous selections from the large collections received from Madagascar have been found to be well suited to our conditions. They have yielded up to 20 and 30 tons of tubers respectively per acre under high fertility conditions and the plants also showed high degree of field resistance to "Cassava mosaic." Both these strains are found to be suitable for home consumption and possess an excellent cooking quality and the skin of the tubers can also be peeled off easily. They take about 8-10 months for maturity. Another high yielding seedling selection (CTCRI-300) producing medium sized stout tubers has been made at the Institute from the Brazilian stock and has been found to be particularly well suited for the industry as it possesses a starch content of about 30% on fresh weight basis. It responds well to high soil fertility, has recorded up to 25 tons yield per acre and also showed a very high degree of field resistance to "Cassava mosaic." Seedling selection (CTCRI-298) from the Malayan material has also been found to respond well to fertilization and is a heavy yielder. Tubers are creamy yellowish, very sweet and possess good cooking quality. It is, however moderately resistant to "Cassava mosaic" under field conditions. Both of them also take about 8 to 10 months for maturity. The material of the above mentioned selections is being adequately multiplied for rigorous testing on an All-India basis under different agro-climatic conditions

INTERVARIETAL HYBRIDIZATION AND SELECTIONS FROM THE HYBRIDS

An extensive intervarietal hybridization programme having varied objectives is also underway at the Institute. Several varieties have been found to be distinctly better combiners than some other varieties. Testing of indigenous and exotic varieties of cassava for their combining ability has been a regular item of the cassava breeding programme. A large number of inter-varietal hybrids have thus been obtained and they are continuously being subjected to statistically laid out yield trials, followed by critical selections based on yield and several other criteria. Inter-varietal hybridization in cassava, if carried out on a large scale, offers great possibilities for selection of plants with desired combinations of characters. Being highly heterozygous, such crosses can be expected to give a wide segregation and allow of considerable scope for selection even in the first generation.

As a result of the large scale inter-varietal hybridization programme at the Institute, the following hybrids namely CTCRI-H. 97, CTCRI-H.50, CTCRI-H 518 and CTCRI-H.86 have so far been selected based on yield, vigour as well as several other desirable characteristics (see also Magoon and Appan, 1966c). These hybrids in yield trials have given tuber yields of 20 to 30 tons per acre compared to 8 tons per acre even under high fertility conditions of the control. These hybrids have also shown high degree of resistance under field conditions to "Cassava mosaic." The tubers have desirable shape, are sweet in taste with low prussic acid content and possess good cooking quality. The material of these hybrids is now being adequately multiplied for further rigorous testing under different agro-climatic conditions.

EVOLVING INBRED LINES IN CASSAVA

In view of the highly heterozygous nature of the indigenous cassava types, perpetuated through years of sexual propagation, it has been suggested that selfing offers a good scope for exposing the locked up variability for selection. Koshy (1947) and Abraham (1957), on the other hand, suggested that evolving homozygous lines in cassava for the purpose of exploiting hybrid vigour offers the most promising line of work in the improvement of cassava. However, several practical difficulties (see also Abraham, 1957) such as variable time of flowering and difference in time of maturing of male and female flowers in a plant, rapid loss of yield, poor flowering and vigour, pollen sterility, etc., even after two to three generations of selfing, etc., are being faced and no less than 6 generations of selfing may be rquired to obtain good homozygous lines in the material under study.

Two points need to be considered in this connection. First, it is not clear whether such a procedure is essential for exploiting hybrid vigour in this crop. For, once a high performing genotype or clone has been established, thanks to the possibility of vegetative reproduction, it can be maintained without difficulty and also multiplied rapidly. Hence, inbreeding which is essentially practised to obtain fixed, repeatable genotypes in seed reproduced taxa may not be an essential step in exploiting hybrid vigour in cassava. Secondly, the great danger of distributing a single genotype over wide areas should not be lost sight of.

It is obvious therefore, that it would not be profitable to employ in cassava the most popular method of corn improvement, viz., producing hybrids of the best combining inbreds, because in maize, which is seed propagated, the objective is a uniform superior population, while in cassava, however, it is the superior individual, which once selected, can be vegetatively multiplied into an agronomically uniform population of any desired size. Further, neither the inbreds by themselves can be expected to satisfy the commercial requirements of the crop. Besides, the inter-varietal hybridization programme between selected varieties of known combining ability which has thus far produced very satisfactory results as described in the preceding section, efforts are also being made to cross one generation selfed lines of selected types with the best pollinator. Production of multiclonal hybrid varieties is also being considered.

INTER-SPECIFIC HYBRIDIZATION

Inter-specific hybridization and genome analysis carried out on different crops have opened up new avenues of improvement of crop plants and have successfully contributed to the development of radically new and better types. However, as compared to other crops, cassava breeders have not yet scratched the surface in utilizing the genetic variability occurring within the species in nature. Added to the genes in the cultivated types are the vast array of genes in related "species" which possess reservoirs of unexplored genetic characters, incorporation of which into the cultivated varieties would appear to be of prime importance in any modern cassava breeding programme. The transfer of characters from one taxa to another is not only of great, potential, practical importance, but is of considerable genetic interest as well. It is therefore, important to extend the limits of transfer as far as possible. In fact, modern advances in cytogenetics, embryo culture, polyploidy, use of bridging species, alien chromosome and gene substitution and other techniques are expanding the range of species from which desired genes can be borrowed so as to make the commercial varieties more suitable to current human needs.

All species of the large genus *Manihot* are confined as wild plants to the American tropics ; no native species are found in the old world (Rogers, 1965). There are certain "species" group in the genus, the progress of speciation among forms of the same group is comparatively weak, so that related species are connected by inter-grades (see Rogers, 1965, Bolhuis, 1949 and 1953), Croizat, 1942 and Jennings, 1959). Very few "species" have been used so far in the breeding programmes and this may probably be due to the non-availability of extensive specific collections at various research centres. However, some useful work relating to inter-specific crossing for breeding improved cassava varieties have been reported. For instance, in Java, Koch (for detailed reference, see Jennings, 1959) reported successful crossing of cassava with *Manihot glaziovii* (Ceara rubber) and *M. dichotoma* (Jaquie *Manicoba* rubber) ; in East Africa, Nichols (1947) and Jennings (1957) described the use of these species together with the tree like species, *M. catingea* and two herbaceous species *M. saxicola* and *M. melanobasis*, *M. glaziovii* has also been utilized extensively in the cassava breeding reported from Madagascar (Cours, 1951). By several generations of back crosses of these hybrids to cassava, new types of cassava, highly resistant to virus diseases, were evolved which led to greatly increased yields (see Ann. Rep. E. African Inst.

at Amani; Nichols, 1947 and Jennings, 1957 & 1963).

Crosses between *Manihot melanobasis* and cassava were very fertile and the fertility was maintained in the hybrids (Jennings, 1959). The first and subsequent generations of these crosses were very high yielding. The species has been found to be a very valuable source of new genes for cassava improvement. He felt that in view of the readiness with which the two species inter-cross, it is doubtful whether their separation as distinct species is justified. Bolhuis (1953) arrived at the same conclusion for *M. saxicola* which also inter-cross freely. In India, Koshy (1947) and Abraham (1957) also reported successful crosses between cassava and Ceara rubber followed by several generations of back crosses with cassava. Chemical analysis of tubers is underway, before they can be released for general cultivation. Recently, Magoon, Jos and Appan (1967) at the Institute have also successfully made this cross using cassava as the female parent and *M. glaziovii* as the male parent. Pachytene pairing was found to be apparently normal and complete along the entire length of the bivalents in the F1 hybrid, with the exception of one bivalent which showed very small terminal as well as interstitial non-pairing segments. One bivalent also showed loose pairing in some regions. Eighteen II's were usually present at MI, though occasionally two to three bivalents showed the tendency to separate precociously at this stage. The average chiasma frequency at MI (mean of 20 cells) was found to be 17.3 per cell. About 15% of the microsporocytes analyzed at AI showed 1 to 3 laggards. A few lagging chromosomes were also noted in about 20% of the cells at AII. One to two micronuclei were occasionally present at the sporad stage. The F1 hybrid showed a very high degree of pollen sterility. The female fertility was moderate. A backcross programme with the cassava parent has also been taken up.

It may thus be seen that considerable scope exists in intensifying the work of inter-specific hybridization in the genus *Manihot*, as large numbers of "species" have been reported in the genus (see Jennings, 1959), but however, as stated above, only a few species have so far been used in the breeding programmes. In fact, very little is known to the breeder concerning the remaining wild forms. In view of the growing importance of the crop in the tropics, cassava breeders will in the near future be faced with increasing demands for high yielding, disease and pest resistant types having several other desirable values and storage qualities and qualities satisfying the demands of the industry. This can be greatly made possible only through intensive collections and assemblage of the entire germ plasm of this genus from areas of origin and centres of diversity and assessing their performance in the various suitable centres of the world dealing with the improvement of this economically important crop. There is an urgent need for international co-operation for collection, maintenance, multiplication and proper evaluation of this vast diversity for effective screening and full exploitation of sources of this genetic diversity in improvement work in this crop.

RESISTANCE BREEDING

The increasing importance of diseases has stimulated considerable interest in resistance breeding. In fact, this is one way of stepping up production by removing the "bottleneck" genes (Joshi, 1963) which tend to limit the expression of the inherent yielding ability of the plant under the influence of unfavourable environmental conditions including diseases and pests. Amongst the diseases infecting the crop, "Cassava mosaic" is a factor seriously limiting production of cassava in India. Though, considerable research work on different aspects of "cassava mosaic" and brown streak have been done in Nigeria, East Africa, Madagascar, Brazil, etc. (see Nichols, 1947 ; Jennings, 1957, 1960 a and b ; Chant, 1958 ; Silva, 1962 ; Jameson, 1964 and others), little attention, has, however, been paid in India to the problem of breeding varieties resistant to "Cassava mosaic" diseases. Intensification of research on all aspects of this virus disease is, therefore, an urgent necessity in view of the ravages that virus diseases cause.

This disease is caused possibly by a complex of viruses. The virus disease syndrome of cassava plants is extremely varied. However, the chief symptom of the "Cassava mosaic" disease is the mottling of the leaves due to degeneration of chlorophyll. In severe cases the leaves become small, curl and get distorted. The leaf blade gets reduced to a narrow strip along the veins ; the internodes are shortened. The plants remain markedly stunted and form few and small tubers. The "cassava Mosaic" is carried by white flies of the genus *Bemesia*, but is also distributed by planting infected stem cuttings.

Adequate control of virus disease in general presents considerable difficulties. Rogueing the diseased plants wherever possible and practical must be practised but this method does not ensure complete success. Similarly, eradication of vectors of the disease is not considered practical. Therefore, the economical and practical method of control is the development of resistant varieties. An essential prerequisite for breeding for disease resistance is the availability of a suitable source of resistance. The desired resistance may be found within the cultivated species itself or only in the related wild species. For obvious reasons, the resistance occurring within the cultivated species is more desirable since it can be more easily transferred to an otherwise superior but susceptible variety. Further, for successful planning of the resistance breeding programme, an appraisal of the mechanisms of resistance and its genetic basis is quite essential. In fact, it is very desirable to secure a reliable picture of genetic mechanism of resistance at as early a stage of the programme as is possible, so that the breeding programme could be appropriately oriented to suit the situation. Routine testing of genetic stocks under natural conditions may lead to evolution of varieties with assured degree of resistance. Considering the economic importance of the disease and in view of the fact that very little attention has been paid in the past to this disease, a comprehensive virus unit has recently been established in the Institute to deal with the "Cassava mosaic" disease and other virus diseases of some other tuber crops. The programme of work on breeding virus resistant, cassava varieties, in general includes :

(1) A survey of the incidence of "Cassava mosaic" in different cassava varieties in various agro-climatic locations.

(2) A study of symptomatology and of the estimate of the losses in yields.

(3) Differentiation of resistant and susceptible genotypes and utilization of the resistant stocks in hybridization programmes.

(4) A study on the biology of the viruses, their modes of transmission, pathological physiology of infected plants and the genetics of the disease resistance.

As already stated, the value of germ plasm collection and the proper way of systematically screening and successfully utilizing it in an active programme of production as well as resistance breeding cannot be over emphasized. Information on disease resistance, both in the indigenous as well as available exotic types, is now being continuously gathered. The Institute is also further exploring the possibilities of collecting superior germ plasm of cassava from several parts of the world so as to screen and locate more and more sources of resistance with a view to increasing the pool of resistance genus for successful breeding of resistant varieties.

The exotic material already available at the Institute is being critically studied from two angles, (i) determining if any, of these exotic varieties could be directly used for cultivation, (ii) effective utilization of these material as breeding stocks. In fact, some of the new selections and hybrid combinations of cassava, viz. CTCRI-300, CTCRI-1310, CTCRI-H.50, CTCRI-H.86 CTCRI-H.97 recently developed at the Institute have shown a high degree of field resistance to "Cassava mosaic" and have also proved to be heavy yielders. They are now being further subjected to extensive laboratory tests to determine the stability of the resistance to virus infection and the stability of agronomic qualities.

GENOME APPROACH TO CASSAVA IMPROVEMENT

A considerable proportion of the forms in various tuber crops with which the plant breeder deals are in fact polyploids which undoubtedly pose many difficulties in their improvement. Boiteau (1941) has reported the natural occurrence of a polyploid series of cassava in Madagascar. Jennings (1963), taking into consideration the chromosome numbers of other genera in the *Euphorbiaceae* together with evidence from studies of meiosis in the species itself, suggests that cassava is an allopolyploid. The polyploids, whether autopolyploid or amphipolyploid, possess highly buffered genetic systems.

The buffering is expressed in polysomic inheritance in autopolyploids and in intergenomic epistatic effects in amphipolyploids with the result that unless a polyploid is reduced to its basic genomes, it may not be easy, unlike in diploids, to treat the problems of intra- and inter-genomic repatterning. What can be achieved when the requisite basic knowledge is available, is strikingly illustrated by the interesting work with wheat where such genome approach has paid considerable dividends. With a view to evaluate this approach in the improvement of cassava, in addition to analysis of interspecific hybrids, a programme of artificial induction of haploidy (see review by Magoon and Khanna, 1963 for terminology classification and utility of haploids) in some of these crops has recently been initiated at the Institute using several techniques including among others, (i) delayed pollination, (ii) use of abortive pollen, (iii) distant hybridization, (iv) high and low temperature, (v) irradiation and (vi) treatment with various chemicals. There is no doubt, however, that their use can be practical only in the crops where they can be produced and screened in fairly large numbers as has been found in commercial potato by Hougas and Peloquin and their collaborators at the University of Wisconsin, U.S.A. (see for review, Hougas and Peloquin, 1958). Recently, analytic breeding, which involves, (a) reduction of a polyploid to its diploid components, (b) intensive breeding and selection at the diploid sporophytic level and (c) resynthesis and testing of the polyploid form, has been critically discussed by Chase (1963) outlining the advantages, operative steps and assumptions involved in this radical approach to the improvement of several polyploid plant varieties. The chief objective is to reverse the evolutionary pathway, from polyploidy back to diploidy, with a view to intensify selective breeding and to set the stage for retracing the evolutionary sequence from ancestral diploidy to polyploidy with genomes moulded more closely to current human needs (Chase, 1964). It is thus apparent from the recent work on potato (see for review, Magoon *et al* 1962) that such an approach particularly in vegetatively propagated crops in which little or no seed production is required affords good possibilities of improvement and re-fashioning the polyploids into forms more suitable to our present needs.

PRODUCTION OF CHROMOSOMAL RACES

Another line of approach in the cassava improvement programme, besides hybridization and analytic methods of breeding, which warrants investigation is the production of colchiploids as well as "triploids." Graner (1941) and Abraham *et al* (1964) described colchicine induced tetraploids of cassava. "Triploids" ($3n = 54$) were also obtained by the latter authors by crossing induced tetraploids with some of the cultivated cassava varieties and they were found to be superior to colchiploids in yield and sometimes outyielded "diploids" ($2n = 36$) also. The relative merits of "triploid" ($3n = 54$) cassavas need study. Triploids have been shown as superior cultivars in several crop plants. Marks (1966) argues that their survival as cultivars means that they possess certain selective advantages as cultivars, advantages often concomitant with triploidy *per se*. Triploid cultivated bananas have been found to be better in productivity vigour, sterility and variability (Simmonds, 1962). In sugar beet and American Apples also, triploids are superior (Allard, 1960). Kihara (1951) reports that intra- and inter-varietal triploid watermelons are much superior to either diploids or tetraploids in yield per unit area. Similarly, Larsen (1954) recommends breeding triploids in Alnus, Betual and Populus because of their superior growth rates and vigour. Marks (1966) suggests that relative merits of triploid cultivated potatoes warrant investigation.

As stated earlier, all cultivated indigenous types of cassava thus far screened possess $2n = 36$ chromosomes. Therefore, with a view to test the yielding potentialities and adaptability of colchiploids, tetraploidy has been successfully induced through colchicine treatment in a few agronomically superior varieties of cassava. The colchiploids possess 72 chromosomes and the material is now being adequately multiplied for large scale yields trials. These induced tetraploids are also being crossed with some of the selected cultivated $2n = 36$ types so as to produce "triploids" ($3n = 54$). A few seeds have already been obtained and will be sown shortly.

MUTATION BREEDING

The use of radiation to produce genetic variants is a useful tool of potential value in agriculture, capable of being employed as an adjunct to conventional procedures. Besides, other uses, this technique has been found particularly useful in rectifying specific defects in otherwise desirable varieties. Other situations in which radiation breeding might be a method of choice are where tight linkages have to be broken or in the introduction of specific characters especially into vegetatively reproduced plants where the extreme heterozygozity is likely to make recombination breeding difficult (Mackey, 1956 and Pal, 1965). Using a wide variety of mutagens, a mutation breeding programme in cassava has been taken up recently at the Institute with the hope that once suitable treatments and handling techniques are refined in this material, this method could also be extensively utilized in future cassava breeding research. The polyploid condition of cassava

(Jennings, 1963) may not be of any handicap in mutation work since recent results with polyploid crop plants (Swaminathan, 1957) suggest that polyploids, because of their greater variability after mutagenic treatment and also because of their greater buffering or homeostatic capacity, might turn out to be particularly suitable material for such methods. The radiation programme has been taken up with the following three objectives in view :

(1) *Induction of mutations in respect of specific characters :*

It is felt that to begin with irradiation of popular and otherwise desirable cassava varieties suffering from any serious defect or defects, like late maturity, non-flowering habit, disease or pest susceptibility, lodging, etc. may be taken up to secure mutants free from these defects and thus rehabilitate the varieties for commercial cultivation. A fairly large amount of material of certain desirable commercial varieties (seeds, varying sizes of stem bits, etc.) of cassava were irradiated with one physical mutagen, viz. gamma rays taking advantage of the facilities of Cobalt 60 source and dozimetry cell at the Indian Agricultural Research Institute, New Delhi. Since the optimum doze of irradiation had not been previously determined, a wide range of treatment has been tried in each case. The material thus treated has already been planted in the field along with the control and is being screened. There appears to be a differential varietal response to the treatments given. L.D. 50 for each variety is being established. Further, treatments with other two physical mutagens viz. X-rays and neutrons are also being taken up. Since it is possible to successfully germinate even a single bud in cassava (the technique of single bud culture has been standardized and also utilized to best advantage among other uses for ensuring rapid multiplication of the cassava material) the chemical mutagens also offer good possibility for maximizing the mutation frequency and the work in this direction has also been taken up.

(2) Induction of haploidy for utility in several basic fundamental as well as applied problems.

Because of the great theoretical and applied potentialities of "haploids", a number of methods including, the use of radiations (pollinations with different dozes of X-ray or gamma rays radiated pollen in hybridization programme in selected varieties having suitable genetic markers with the hope of providing stimulus to the egg to develop parthenogenetically) is being tried for the artificial production of "haploids" in cassava.

(3) To study the spectrum and nature of mutations induced by different mutagens in different genotypes.

Since the success in mutation breeding would depend on the frequency and variety of mutations induced, the treated material will also be studied in regard to types of mutations induced by different mutagens and treatment methods.

SUMMARY

The range of available genetic variability in the crop is presented. The opportunities of further improvement of cassava, through efficient exploitation of the germ plasm reserves available, seem exceedingly great. The need for conducting combined study of morphological, cytological and genetical aspects in arriving at a more natural, botanical classification based on ancestral relationships

has been stressed since such knowledge is indispensable to the breeder and also finds important applications in certain other fields. Problems and approaches of current interest in relation to production and resistance breeding have been discussed. The chief characteristics of the selections and high yielding hybrids recently developed at the Institute are briefly described. Work relating to inter-specific hybridization, production of chromosomal races and mutation breeding and their implications in the cassava improvement are briefly reviewed. The genomic approach to cassava improvement has been discussed. It is suggested that the separation of the intragenomic and intergenomic phases of plant improvement offers the cassava breeder considerable scope for better genetic control than presently obtained.

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DISCUSSION 4

Dr. Rogers :

I would like to ask you, and perhaps all of the others who have been here, this question. Do you have any difficulty in getting a suitable arrangement for selfing these plants ? It has been my experience, that you do not have inflorescence on the plants where the female and the male, are open at the same time. How do you go about using inbreeding as a method in the improvement of cassava and how ?

Dr. Magoon :

As regards flowering of cassava, it may be pointed out that a good number of cassava types have never been known to flower. Sterility is also common in this crop which has been propagated by vegetative means for thousands of years. As a result of screening, a varying degree of male sterility has been recorded among the available cassava collection at our Institute and as stated, previously, thirty five types have been found to be completely male sterile. Attempts are underway to study the physiology of flowering and on the whole, it is aimed at

(1) synchronisation of flowering in varieties to be hybridised.
(2) making non-flowering and shy flowering varieties to bloom for crossing purposes and also facilitating crossing, if possible during the whole year around.

We have also in our cassava collection several types which flower normally and the normal plants being monoecious, the female flowers at the base open first and the male flowers at the top do not mature until 8 to 10 days later. Selfing up to 2 to 3 generations can be managed somehow in the face of practical difficulties such as variable time of flowering and difference in time of maturing of male and female flowers in a plant, rapid loss of yield, poor flowering and vigour, pollen sterility etc. In order to do further selfing, vegetative multiplication needs to be interpolated and no less than six generations of selfing may be required to obtain reasonable homozygous lines in the extremely heterozygous indigenous cassava material under study. The plants become weaker and weaker and flowering becomes scarce after the fourth generation of selfing. Based on the inbreeding work done so far and in view of the important points raised in the text of the paper against evolving homozygous lines in cassava, for the purpose of exploiting hybrid vigour in this crop, it can be emphasised that pure line crossing in cassava could not prove to be useful as a means for producing improved strains in this crop.

Dr. Rogers :

May I ask a question on your work. I am, first of all, quite interested to note, that you picked up another character for which I am very glad you did, namely, the lenticels on the surfaces of the rough rooted group. I do not know how I happened to miss that but I am glad that you found it.

Dr. Montoya :

I would like to mention, that in some cases, in Latin America, it is very difficult to find a reference on publications in relation to manioc and cassava and I would like to ask all persons engaged in cassava research to interchange publications and planting materials.

Dr. Bolhuis :

Dr Rogers asked about the flowering of cassava. When plants are grown at low altitudes in Bogor Java, they do not flower but produce very tall plants. However, when they are grown at an altitude of 3,000 feet they flower profusely and pollinations could be made without the aid of ladders.

Dr. Rogers :

I think that you can get around this far easier in another direction if you like. Purely by accident, I discovered that if you let cattle into your experimental plot, the chewing off of the apex of the bud has a considerable effect towards the flowering.

ANDEAN TUBER AND ROOT CROPS: ORIGIN AND VARIABILITY

— *by* —

Jorge Leon
IAIAS — Andean Zone

The human occupancy of the Andean highlands is more than 10,000 years old. If the common theory is accepted that man came to America through the Bering strait and dispersed southwards, then the Andean highlands offered to early man a series of habitats that were somewhat similar to the northern part of Asia. The cool, barren punas were excellent hunting grounds The auchenids: guanaco, llama, vicuna and alpaca, supplied him with abundant meat and furs. The open country covered with grass, in the belt between the 3000-4000 m., with clear streams and many caves, was probably the first area in which man settled permanently in the Andes. The remains of El Inga in Ecuador and the caves of Lauricocha in Peru, show that hunting was the predominant activity of the Andean man 8000-6000 years ago.

In the high Andes the frost-free period determine the growing season. Only few plants, grasses like *Stipa,* could grow continuously. The majority of the species have developed extensive subterranean organs, storage roots or tubers, which are permanent; during the frost-free season they put up few leaves and flowers, the latter comparatively large. All the aerial parts are eventually destroyed by frost, which marks the end of the growing period. In the tuber plants, the underground organs continue to grow for some period after the aerial parts have died; they are ready to sprout again as soon as the frost disappears in the next growing season. This process is so efficient, as a means of survival, that many plants in the Andean habitat usually do not set seeds and depend on tubers for their propagation.

Sauer (10) has pointed out how easy it is for primitive man to start using tubers as food. In the Andes two factors may have contributed to domestication. First, it is possible that in the original systems of cooking meat, using hot stones ("pachamanca") with earth piled around, some tubers could be casually cooked, and eventually eaten. In this form tubers and roots were consumed for a long time before the invention of pottery. A second factor is that the Andean tubers and roots present very attractive forms and coloration; primitive man may have collected them for such characters, and then tried them as food.

ANDEAN ROOTS AND TUBERS

Vavilov (11) has given a long list of cultigens which he supposed originate in the Andes. Many of them, we know now, are introductions from other areas, assembled by expeditions and interchange, particularly during the expansion of the Inca Empire. This vast political unit covered from north to south an area longer than from Norway to Spain. However, all the tubers listed by Vavilov are undoubtedly of Andean origin. The most important are the potatoes; but there are others, like oca or cubia, *Oxalis tuberosa;* ulluco or melloco, *Ullucus tuberosus;* mashua or isano, *Tropaeolum tuberosum,* which are of local importance. Besides there are: maca, *Lepidium meyenii,* a root or rather a tuberous hypocotil now a relict crop; and among the true roots, arracacha, *Arracacia xanthorrhiza;* yacon, *Polymnia sonchifolia;* jicama, *Pachyrrhizus ahipa.*

In some Andean plants the fleshy and edible tissues extend from the roots to the lower part of the aerial stems, which in turn are of the same colour and structure and also edible. Such happens commonly in the yacon and the mauka, *Mirabilis expansa,* the latter recently discovered in cultivation by Ing. Julio Rea, first in Bolivia and later in Ecuador.

From Venezuela to northern Argentina, the Andean tuber and root crops grow at different altitudinal levels: oca, ulluco, mashua, maca and some potatoes above 3000 ft.; arracacha and yacon from 2000 to 4800 ft.

In the vast area occupied by these crops it is difficult to delimit specific centers of origin. For potatoes, oca, ulluco and mashua, the highest concentration of present variability is located between Peru and Bolivia. It is also in this area, where more wild *Solanum* are concentrated. Wild ullucus are still found in these two countries. No true wild oca has ever been found. In reference to mashua the picture is more complicated, as several species of edible *Tropaelum* have been reported from Colombia to Patagonia, and this group needs a careful revision to determine the different species. The facts mentioned above support the hypothesis of Cook (4), Bukasov (1) and others on the altiplano origin of these crops, which seems more likely than the new idea expressed by Sauer (10), which supposes that most of the Andean crops were domesticated in northern South America.

THE ANDEAN POTATOES

In the Andes there are several species of potatoes that are cultivated regularly; others which are collected occasionally and many wild species of tuberous *Solanum* without any economic use. The classification of the Andean potatoes is, in spite of the efforts of taxonomists and geneticists, still quite confusing. There are several factors that contribute to this situation. The cultivated potato shows different levels of ploidy: 2x, 3x, 4x and 5x; they grow in very different habitats, from 3000 ft. to the highest level of vegetation; it is possible that through hybridization and introgession, wild genes may be introduced in this complex. The taxonomy is still a matter of controversy. Bukasov (2) considers as species 5 diploids: *S. stenotomum, S. goniocalyx, S. ajanhuiri, S. phureja, S. rybinii;* several triploids; *S. chaucha, S. tenuifilamentum, S. mammilliferum, S. chocclo, S. cuencanum;* two tetraploids: *S. tuberosum, S. andigenum;* one pentaploid: *S. curtilobum.*

According to Dodds (6) there is one species, *S. tuberosum,* divided in five groups: *stenotomum, phureja, chaucha, andigena* and *tuberosum;* a triploid hybrid: *S.* X *juzepczukii,* and a pentaploid hybrid: *S.* X *curtilobum.*

Hawkes (8) recognizes 3 triploid species: *S. ajanhuri, S. phureja, S. stenotomum;* a tetraploid: *S. tuberosum;* two triploid hybrids: *S.* X *chaucha, S.* X *juzepczukii;* one pentaploid hybrid: *S.* X *curtilobum.*

MINOR TUBERS

The oca or ibia, *Oxalis tuberosa,* is the second tuber of importance in the Andes: it is cultivated from Venezuela to northern Argentina. Outside this region it is found only in Mexico, New Zealand and occasionally in southern Europe. Ocas are short, compact fleshy plants, formed by several stems that sprout from the mother tuber. The leaves, as in other species of *Oxalis*, are formed by a long petiole with the blade divided in three parts like clover. The yellow flowers show a marked heterostily; they drop a few days after anthesis and very seldom set seed.

The tubers are cylindrical or ellipsoidal, very fleshy, with long, shallow "eyes." Their colour ranges from yellow to purple, uniform or more intense around the buds. Unlike the potatoes, the skin is soft. Many varieties are quite sweet and eaten raw, but most of the tubers are cooked or prepared in chuno.

Ocas are extremely variable. In the Andean Zone collection there are around 150 introductions. They originate mainly from bud mutations.

Ulluco or melloco, *Ullucus tuberosus*, belongs to the Basellaceae. The cultivated types are short and compact, while the wild plants have long, climbing stems. The leaves, cordate and thick, are bright green, often with yellowish areas in the margins. Aerial tubers are found sometimes in the axils of the leaves. The star-like flowers of opaque-yellow colour, grow in racemes; the fruits are capsules containing one seed.

The tubers are cylindrical, ellipsoidal or spherical, with shallow eyes. The most common types are golden yellow, which turn green when exposed to light. In these clones chimaeras are common, appearing as spots, lines or relatively large areas of deep purple. There are also cultivars with white, green, coral, pink, brown or purple tubers. Some varieties may be confused with potatoes, as they have a dark colour and a velvety surface. The skin is soft, and the flesh yellow and mucilaginous. Ullucus are always cooked; they are consumed in large quantities in the cities, and appear in plastic containers in the best supermarkets.

There is an ample variation in this species, concentrated in the Peruvian-Bolivian area.

The third among the lesser tubers is the anu, isano or mashua, *Tropaelum tuberosum*. This plant resembles the common nasturtium, although it is more compact and has smaller flowers. The stems are green or reddish, and the leaves show a considerable variation in form; they are peltate, with 3 to 5 lobes. The flowers, like in nasturitium, have long peduncles. The red calyx forms a spur, in some cases two. The orange petals are of different size and shape. The mashua commonly set seeds.

The tubers are long, generally deeply furrowed, each furrow corresponding to an eye. The coloration varies from transparent white to almost black. Some very attractive types have tubers with a deep yellow background with some areas covered by fine points or lines of brown or purple.

The mashua tubers are always cooked; they taste like turnips. In some Indian communities, where potatoes or other tubers do not grow, mashuas are a primary article in the diet. This species may grow at higher altitudes than the other tubers, due to its resistance to cold. Mashuas are also frozen after cooked, and in this way they are more agreeable and nutritious.

Several hundred clones of mashua are known. It has been proposed to separate them in two species: one would correspond to the Colombian types, characterized by long, deeply furrowed tubers, white with pink extremes, with numerous rootlets; the second to the Peruvian-Bolivian types, with yellow tubers, often with dots and lines, and without rootlets. The characteristics mentioned do not seem, however, to justify the specific separation.

ROOT AND CORM CROPS

In the Andean area several root and corm crops have been domesticated. Others like the achira, *Canna edulis*, although of very ancient use, may have been introduced from the lower regions (7).

Maca, *Lepidium meyenii*, is a turnip like plant which grows at the highest elevations (3500-4000 ft.), above the level at which the common potatoes and the other tubers are planted. The plant exhibits the typical habit of the puna plants: a rossete of dissected leaves, attached to the ground, and a thick hypocotyl, the edible part, rich in starch and sugars. Macas are propagated by seed; its culture is disappearing rapidly (9).

Arracacha, *Arracacia xanthorrhiza*, is the only Umbellifer domesticated in the New World. It has been introduced to Central America, West Indies, the highlands of Africa and Ceylon, where it grows well above 600 m. It is also produced commercially in the subtropical area around Sao Paulo. The arracacha is a vigorous plant, up to 2 ft. high, with dark green or purple foliage. The edible part are the roots, and in some cases the underground stem. The roots are starchy, highly aromatic, and are eaten cooked in different ways. According to Bukasov (1), "The natives rightly appreciate the flavor of arracacha which is superior to potato, as the insipid taste of the potato, is supplanted in the arracacha by the aroma of the umbelliferae, in a moderate degree (different from celery), which makes arracacha not a condiment but a food, which can be used in a pure state".

The fusiform roots, up to 15 inches long and 3 inches wide, are white or purplish outside. The inside is white or yellow, often with purple areas. The transversal section shows a ring of purple dots and mucilage channels, separating the cortex from the central core.

The center of variability of arracacha lies in central and eastern Colombia. In cultivation it extends to southern Bolivia. Although there are several wild species of *Arracacia* from Colombia to Peru, there is no information on the relationship of the cultivated arracacha and these wild species, neither is it found anywhere in native state.

Yacon, *Polymnia sonchifolia*, is a typical Andean Cultivar. It grows from Venezuela to northern Argentina, from 3000 to 7500 ft. Nothing is known about its origin; Bukasov (1) says it grows wild in Colombia.

The edible parts in the yacon are the roots and the fleshy part of the lower sections of the stem. Both have a soft, purplish bark. The flesh is transparent yellow, and contains insulin-like sugar. The fusiform roots are harvested, stored in a dry dark place. They are eaten fresh and have a typical sweet taste. Starch is completely absent. Cobo (4) says that in the colonial times, the roots were taken in the long trips by boat to Spain, and they lasted for months in good conditions.

The yacon is propagated vegetatively by sprouts. The plant produces several aerial stems, with abundant foliage; as leaves and stems contain between 12 to 16% of protein, the yacon could be used, like the topinambur, as a forage plant.

Jicama or aricoma, *Pachyrrhizus ahipa*, is the Andean counterpart of the Mexican jicama, *P. erosus*. It is restricted to Bolivia and northern Argentina, while *P. tuberosus* according to Clausen (3) is the species found in the highlands of Eucador.

The jicamas have one or several vines arising from a subterranean, fleshy root. The leaves are divided in three leaflets, often of different shape in the same plant. The seeds have been used as an insecticide.

The watery sweet roots are the edible part. They are eaten fresh, and are consumed in great quantities in Bolivia and Ecuador. In Peru they are unknown at present, although jicama was an important crop in the pre-Spanish period.

COMMON CHARACTERISTICS OF THE ANDEAN TUBER CROPS

1. The tuber crops originated at high altitudes — potatoes, oca, ulluco, mashua-offer a great similarity in morphological and physiological characteristics. By convergent evolution, tubers of certain cultivars of oca, potatoes and ulluco, are practically not distinguishable to the common observer. They are similar in size, shape and superficial texture. Areas with red or purple pigments are found in all of them, varying from a solid patch covering a good part of the tuber, to tiny lines or dots. The presence of red-purple pigments is a common feature in many Andean plants.

2. In the Andean tubers, vegetative propagation is the rule; potatoes and mashuas regularly set a good number of seed.

3. The growth process is quite similar in the tuber species mentioned above. It is determined by a short growing season from 6 to 7 months, between the frost periods; by high day and low night temperatures, and high insolation. Measurements of the weight of vegetative parts, under experimental conditions, in Andigena potato, ulluco, mashua and oca, show roughly similar curves. In all of them there is a marked increase in the first two months, then a resting period of very short duration, followed by a final increase in growth, far more important than the first.

4. The start of tuberization corresponds in these species approximately with the blooming period, and the tubers continue increasing in size after the frost has killed the tops of the plants.

5. The uses of the Andean tubers are quite similar. They are eaten primarily cooked, as vegetables. Freezing and drying to convert the fleshy tubers in a dry mass ("chuño") is practiced with potatoes, ocas and mashuas.

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SOME EDIBLE RHIZOMATOUS AND TUBEROUS CROPS OF INDIA

— *by* —

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Many types of rhizomatous and tuberous crops are found in different parts of India. Most of them are not indigenous and have been brought to this country from South America, North America or Malaya. Although all of them are not used as food, there are quite a number which can be profitably utilized as food. In the present context of rapid increase of population and consequent shortage of food grains in India, improvement and increased production of various types of tuberous crops as food supplementing the cereals are considered very essential. In view of this, a survey has been made on the wild and cultivated rhizomatous and tuberous crops of India other than potato which can be used as food in supplementing cereals. An account of such crops is briefly presented in this article. Such root tubers as turnip, beet, carrot and radish which are mostly used as vegetables have not been dealt with here.

ALOCASIA

Alocasia belonging to the family Araceae is a genus of herbs bearing short succulent rhizomes or rootstocks with large leaves. There are about 65 species distributed in tropical Asia of which 12 are found in India. Of these *A. cucullata* Schott, *A. indica* (Roxb.) Schott and *A. macrorrhiza* Schott are cultivated for their edible rootstocks. The rhizomes of *A. fornicata* Schott found in village shrubberies are often eaten by poorer classes of people.

Of the three cultivated species, *A. indica* is most important. It is a tall aroid with an underground rhizome bearing a succulent swollen stem, 10-20 cm in diameter and about 30 to 60 cm or more in length. It is cultivated in many parts of India, particularly in Assam and Bengal and is widely used as a vegetable. When the rootstock is pulped and washed, it yields a pure white starch. The flour, obtained is a light and nutritious food suitable for invalids. It is more or less mucilagious and is more easily digestible than rice.

AMORPHOPHALLUS

The genus *Amorphophallus* belonging to the family Aroideae has about 90 species of perennial or biennial herbs usually bearing one broad, long petioled leaf. All the species bear corms. In India there are only 14 species, of which *A. campanulatus* Blume is the only edible species. It is cultivated throughout India and Ceylon. The underground corm is more or less hemispherical or sometimes somewhat elongated, 20 to 30 cm or more in diameter and is of a dull brown or yellowish brown colour. The corms usually weigh from 1 to 2 kg and sometimes as high as 5 to 10 kg in some parts of Bombay. The tuberous outgrowths from the fully developed corms are planted during May and June. Not much care is needed after planting. They mature in about 10 to 12 months when they can be dug out.

Usually pieces of corms are boiled in water and eaten with rice as such as boiled potatoes or in curries.

CANNA EDULIS

It is a handsome rhizomatous perennial herb, a native of Tropical America and is cultivated in various parts of the tropics for the tuberous edible rhizomes from which a kind of arrowroot starch is produced. The plants can grow on most types of soils, and under favourable conditions heavy yields of rhizomes are obtained. The tubers and tops of plants are used as stock-feed and the starch is used as a food for children and invalids.

CASSAVA OR TAPIOCA

Manihot esculenta Crantz (syn. *M. utilissima* Pohl.), commonly known as Cassava or Tapioca, is a low shrubby plant with a cluster of tuberous roots. It is a native of South America from where it has been introduced to India, Africa and S. E. Asian countries. In India cassava is grown as a subsidiary food crop mainly in the States of Kerala and Madras, where the area is roughly about 500,000 acres. In respect to acreage, it ranks second in importance among the tuber crops of India.

Since the beginning of World War II when supplies of rice from Burma and starch from western countries were very much disturbed, cassava was considered as an important crop in India and had been tried in many other States besides Kerala and Madras, but unfortunately it did not find much favour with the people of most areas.

Cassava has several varieties and for edible purposes, strains with high starch and protein content and little or no hydrocyanic acid are usually cultivated. Cassava prefers a warm, humid climate with ample rainfall. It does not stand frost and usually cannot be grown above an altitude of 900 m. A fairly well-spread rainfall of about 150 cm is considered to be optimum for the growth of the crop.

In India cassava is usually grown as a pure crop, but it can be grown as a mixed crop with vegetables, banana or sweet potato. In Brazil the writer has seen cassava grown as a mixed crop with high land paddy. Such trials should be undertaken here.

Cassava is propagated by cuttings of stems after the advent of monsoon. After the field has been thoroughly prepared with the application of a basal dressing of farm yard manure, small pits are dug up to seven to eight cm. apart in which the cuttings are planted in a vertical position one in each pit. Fertilization of the soil by the application of organic manures and or inorganic fertilizers is necessary, as cassava is an exhaustive crop.

The yield of tubers under Indian conditions varies from 1 to 12 tons per acre. In trial under intensive cultivation in Kerala, yields up to 20 tons have been obtained.

COLEUS PARVIFLORUS

It is a small herbaceous annual, 1–2 ft high with succulent stem and aromatic leaves. It bears a cluster of dark brown tuberous roots. The plant is grown in India, Ceylon, Java, Indo-China and parts of tropical Africa for the small edible tubers which are used as a substitute for potato. In India, it is usually grown in the south, particularly in the Malabar Coast. The plants are propagated generally by suckers obtained from germinating tubers. The suckers are planted with the onset of rains in May/June and harvested in December/January. The plants are almost free from pests and diseases. The average yield is about 2000 to 2500 kg per acre but under suitable conditions yields as high as five to six tons can be obtained. The tubers which are small and blackish brown in colour, are starchy with an aromatic flavour. They have a sweetish taste and are used in the same way as potato in curries and in other preparations

COLOCASIA

Colocasia is a small genus of 13 species of perennial herbs of which five to six are reported from India. Only one species *C. esculenta* (Linn) Schott* a plant considered to be a native of S. E. Asia, is extensively cultivated in India. It is a very variable perennial rhizomatous plant with large heart-shaped leaf blades borne on long petioles 30 to 200 cm high. Numerous varieties are known, differing in the colour of leaf blades and petioles and the size, shape, colour, palatability and nutritive value of the tubers. Two principal groups can be differentiated, one with deep purple laminas and petioles and the other in which these parts are green. The sizes of tubers vary considerably in different varieties from small, roundish ones, 2–4 cm in diameter to big and elongated tubers 15 cm in diameter and up to 60 cm in length. The flesh of the rhizomes vary from white to yellow or orange to red or purple.

The plant is propagated by suckers or corm tops or branch tubers. These are planted 8 to 12 cm deep in rows 30 to 60 cm apart with gaps 20 to 30 cm in each row. The method of planting varies according to variety and locality. The usual planting period is from February to July, although it can be planted throughout the year. Manuring is usually done with cow-dung or with mixtures of chemical fertilizers wherever available. The crop has a growing period of four to eight months, depending on the variety used. During this period, weeding is done by occasional hoeing. The crop is harvested when the leaves begin to turn yellow. The tubers are either pulled out by hand or dug up with a spade. After cleaning, the main corms are separated out from the side ones. The yield varies considerably. It may be as low as 1000 kg per acre or as high as 8000 kg under favourable conditions.

The rhizomes are very rich in starch and are used in the same manner as potato. They are somewhat sweeter and more easily cooked than potatoes. They can also be used as fried chips in the same manner as potatoes. The flesh has a delicate, nutty flavour when cooked and is more nutritious than potato, being richer in carbohydrates and proteins. It is also a good source of calcium and phosphorus. When steamed the rhizomes contain 30% starch and 3% sugar and becomes an energy giving good food. In such condition this is liked very much by the people of Northern India.

CURCUMA

This is a genus of 70 species of rhizomatous herbs distributed in India, Siam, Malaya, Archipelago and N. Australia. About 30 species occur in India of which only two, *C. angustifolia* and *C. zedoaria*, are useful in the production of starch.

C. angustifolia Roxb. — The plant usually grows wild in many places but is also cultivated in some areas particularly in the southern parts of India. Yield of about 2000 kg per acre has been reported from trials conducted in Madras. Starch usually prepared from the tubers, resembles arrowroot starch to some extent and is easily digestible. It is used in the preparation of milk puddings and is suitable for children and invalids.

C. zedoaria Rosc. — The plant, a native of N. E. India, is widely cultivated in many parts of Ceylon and China for the production of a kind of starch commercially known as *'shoti'*. The plant grows to a height of about 1½ ft and bears green leaves with brownish purple veins. The rhizomes are large and fleshy. The *shoti* starch is a product extracted from the rhizomes and is used as a substitute for arrowroot and barley. It is highly valued as an article of food especially for infants and convalescents. It is also occasionally used in confections.

DIOSCOREA

Dioscorea is a very large genus of annual twining herbs. Of the 50 species found in India only a few are cultivated for their edible tubers which are called 'yams'. The genus has been classified by Prain and Burkill into two broad divisions: (i) those with stems twining to the right and (ii) those with stems twining to the left. There are about seven edible species in India out of which *D. alata* Linn., *D. glabra* Roxb. and *D. oppositifolia* Linn. come under the former group and *D. bulbifera* Linn., *D. esculenta* Burkill, *D. pentaphylla* Linn., and *D. hispida* Dennst. come under the second group. The edible *Dioscoreas* are cultivated mostly as garden crops or as subsidiary crops with ginger, turmeric, sweet potato or maize.

They grow well in sandy loam soil with proper drainage facility. As the crop is exhaustive, the field is manured liberally with farmyard manure. Both underground tubers and aerial tubers (bulbils) borne in the axils of leaves are used for propagation. These are usually planted from April to July with the onset of first showers of rain. The vines may be allowed to grow on the ground or are trailed over stakes or they may twine on trees nearby. The yield of tubers is usually higher when they are allowed to grow on stakes or on trees. The crops mature in five to eight months time. During this period, the field is hoed and weeded and irrigated whenever necessary. When the tubers are fully developed, the leaves dry up. At that time, the stems are cut and the tubers dug out. The tubers are very variable in size and shape. They are either solitary, one on each plant, or a number of them are clustered together at the base of the plant. The yield of the tuber is also very variable and depends on the variety cultivated and on the soil and cultural treatments. Yields of the two important species are as follows :—

(i) *D. alata*: 2.5 to 14 tons with an average of 7 tons per acre.

(ii) *D. esculenta*: 5 to 11 tons with an average of 8 tons per acre.

Wherever the tuber is solitary, a single tuber may weigh from 2 kgs to 20 kgs. The tubers are comparable to potato in taste and in quality and are used in the same way as potato. They form a cheap source of carbohydrate food and are extensively used by the hill tribes in the uncultivated tracts of certain parts of India. They are of great value during periods of scarcity of cereals.

Starch is extracted on a commercial scale from the tubers of *D. alata*. Some tubers are used for alcohol production. They are poor in protein, calcium and iron content, but they are rich in vitamins of the B group.

Some of the nonedible tubers, as for example, the tubers of *D. deltoidea* Wall. and *D. prazeri* Prain and Burkill, have steroidal saponins which yield diosgenin on acid hydrolysis; the latter forms a starting material for the partial synthesis of sex-hormones and cortisone.

ELEOCHARIS

E. dulcis Trin. (*Syn. E. tuberosa* Schult) belonging to the family Cyperaceae is a stout, leafless sedge bearing a rounded corm or tuber at the base from which a large number of radiating stolons each ending in a corm are developed. The plants are normally found in marshes end moist places almost throughout India up to an altitude of 3000 ft. It is propagated by cuttings and corms. It is more commonly cultivated in China, Japan and Malaya. The tubers are dark brown in colour rounded or onion-shaped, 1 to 1.5 cm in diameter. They are rich in starch and also contain some protein and sugar. They are considered as nutritious and eaten widely. The flesh of the tubers is white and of uniform consistency. They are also cooked and served in salads and soups. They are considered as a delicacy by certain section of people. In India its cultivation is only in small scale and so no yield data are available. A cultivated variety of *E. dulcis* grown in China bears larger tubers (2.5 — 4 cm diam.) and gives a yield up to about 9 tons per hectare.

HELIANTHUS TUBEROSUS

H. tuberosus, a native of North America, and commonly known as Jerusalem artichoke, is an erect hardy perennial crop, which behaves as an annual under cultivation. It is cultivated for its edible tubers, throughout the temperate regions of many parts of the world. In India it is grown in the hill stations at an elevation of 300 to 800 m. but can be grown up to 1300 m. It can, however, be grown under a wide range of soil and climatic conditions. It can also be produced successfully even on lands unsuitable for many other vegetable crops. It is, therefore, possible to extend its cultivation in many newer areas.

The tubers have many varieties and somewhat resemble potatoes, but with larger eyes. From the point of view of food value, the tubers are considered equal to potatoes. They are eaten raw or boiled or as fried chips.

The plant is usually propagated by tubers in well prepared soil liberally manured by farmyard manure or compost. Whole tubers or pieces with two to three eyebuds are planted about six to eight cm deep in rows during March to May in the plains and February to April in the hills. During early stages of dry weather, irrigation is necessary. The crop takes four to seven months to mature. The yield of tubers is from 4 to 10 tons per acre; higher yields have been recorded under favourable conditions.

IPOMOEA BATATAS

I. batatas, the sweet potato; a native of tropical America is being grown for many years in different parts of India and ranks third in importance among tuber crops. Breeding and agronomic works have been carried out in several places for the improvement of the crops. Besides, improved varieties have been obtained from China and U.S.A. Sweet potatoes cultivated in India may be grouped under two main types broadly distinguished by the colour of the tuber coat; they are the white-skinned types and the red-skinned types, the colour of the flesh being white in both. Another type with a golden yellow flesh has been introduced from America in certain areas. Sweet potato is propagated vegetatively by cuttings of the vine obtained from the previous years crop or by sprouts raised from tubers. The former methods is cheaper and is usually practised. The average yield of tubers varies from 4000 to 12,000 kg per acre. Several improved varieties have been evolved by the Indian Agricultural Research Institute. Under proper management such varieties are reported to yield 15,000 kg or more per acre.

Sweet potato is grown more or less in most of the States of India, the total area being about 400,000 acres. It is most extensively grown in the State of Bihar when the area is nearly half of the total Indian acreage.

In India, sweet potato is used as food after boiling, baking or frying and as a vegetable in curries and other preparations. The dried tubers are often ground into flour and mixed with wheat flour for preparing hand-made bread locally known as *'chapati'*. They are also used in various confections.

MARANTA ARUNDINACEA

This is a native of tropical America. As its rhizomes supply the true arrowroot of commerce, its cultivation has spread extensively to many tropical countries including India. In India the area under cultivation is comparatively less. Two types, blue and yellow, called according to the colour of the rhizomes, are usually grown. The yield of starch from the blue type is higher than that of the yellow type.

The plant, grown best in light, well-drained loamy soil, is propagated by means of rhizomes. Planting is done in May. Irrigation is necessary during the growing period. The rhizomes are ready for harvest after about 10-11 months after planting. The yield of rhizomes varies from 4-7 tons per acre, although much higher yields (12 tons) have been recorded under favourable conditions.

The rhizomes are mostly used for production of starch. The true or West Indian arrowroot forms an important ingredient for the preparation of infant foods, biscuits, cakes, puddings etc. They are also eaten boiled and roasted.

PACHYRRHIZUS

This is a tropical American genus consisting of only a few species. One species, *P. erosus* (Linn.) Urban (syn. *P. angulatus* Rich. ex DC) is cultivated in several areas of India for its fleshy tuberous roots. The plant is a native of Mexico and Central America and has now been naturalised in various tropical regions of both the hemispheres.

The plant grows well on light rich sandy loam soils with good arrangements for drainage. The soil should be liberally manured about a month before planting of seeds, by means of which the plant is usually propagated. About 18 to 20 kg of seeds are required for an acre. The seeds are sown usually in June/July at a distance of 30-40 cm in rows which are 60-75 cm apart. The crop reaches maturity in about six to eight months after planting. In order to encourage better development of tubers several pruning operations are undertaken to partially check the vegetative growth. The tubers are obtained before the seed pods mature and at this time the tubers are tender and crisp. The tubers are white in colour and are very variable in size and shape being roundish or lobed, turnip-like or elongated. The tubers sold in market may weigh from about 200 grams to about 1 kg each, but fully developed tubers measuring about 40 cm in diameter and weighing about 5 to 15 kg are known. The average yield of tubers is about 3000 to 4000 kg per acre. In some parts of Indonesia and Philippines yields as high as 95 tons per hectare have been reported.

The tubers are delicious and cooling in effect and are eaten raw. They can also be sliced and made into chips. They are highly nutritious and contain protein 1.47, fat 0.09, starch 9.72, reducing sugars 2.17, non-reducing sugars 3.03, copper 0.43, iron 1.03 and calcium 16.0 mg/100 g. Vitamins viz. thiamin, riboflavin, niacin and ascorbic acid are present in varying proportions. The tubers are also used as fodders. Mature tubers also yield a starch of superior quality.

SCIRPUS KYSOOR

The plant produces small, edible tubers of irregular shape one to three cm in diameter. These are sweetish and very tasteful. It is found under wild conditions more or less throughout India and is sometimes cultivated in some areas in Upper Gangetic Plains. In taste they are comparable to that of the tubers of *Eleocharis dulcis*.

XANTHOSOMA MAXIMILANI

This is a Malayan aroid which has been recently introduced into India. The plant grows under semi-aquatic situations and produces rootstocks 20 to 40 cm long and 6 to 10 cm in diameter. The corms are not fibrous and when boiled become very soft and non-mucilaginous and are tastier than other tuberous aroids.

This plant is cultivated only on a very small scale in certain parts of Bengal and Bihar.

SOME ASPECTS OF SWEET POTATO BREEDING AT THE KABANYOLO UNIVERSITY FARM

— *by* —

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The sweet potato (Ipomoea batatas) has received little research attention in East Africa, apart from variety trials (15), some fertilizer experiments (16) and work on virus diseases (4, 8, 9, 10, 11, 12).

In 'Agriculture in Uganda' (13) Biggs gives a general review of the crop, Hargreaves has a comprehensive section on the more important pests and Hansford covers briefly the diseases, (it is interesting to note that virus diseases are not mentioned in this section, which was published in 1940). Nye recorded in 1937 the names of forty seven sweet potato varieties grown at Bukeka mutala, Bulemezi, Buganda (7), of which only sixteen were included in a variety trial of fifty six varieties at Kawanda Research Station in 1955 (15)

Virus diseases of sweet potatoes have received some attention. Hansford first reported virus disease on sweet potatoes in Uganda in 1944 and suggested that it was transmitted by Bemisia spp (4). More recent work has been done by Sheffield at Muguga in Kenya (8, 9, 10, 11, 12). There is a useful review of this aspect by Martin in 1957 (6).

At Makerere, Aldrich worked on sweet potatoes from 1957 to 1960 and produced an extensive review of the crop in Uganda (2). Aldrich also produced a paper (1) on sweet potato field experiments which recorded his work at Kabanyolo on tuber formation, virus effects, spacing and fertilizers.

The work on sweet potatoes carried out by the writer commenced in 1961 when it was decided to continue Aldrich's husbandry investigations and also, after discussions with the Senior Botanist (G. Thomas) at Kawanda, to investigate the apparent deterioration and replacement of varieties.

After some time the emphasis changed from the husbandry to the breeding aspects.

MUTATIONS

Prior to 1961 it was assumed in Uganda that mutation was the source of new varieties and that virus diseases were the cause of deterioration of the existing varieties.

In 1961 examination was made of the sweet potato clone Bitambi, which is grown on a field scale at Kabanyolo, to determine whether the clone was genetically pure and to detect possible mutants. No significant morphological variations were observed either in the flower or the leaf. Records were kept of fifty-two parent plants and their progeny, but there was no evidence of any mutants in the selected material, although the individual plants responded markedly to environment.

During the investigation into mutations it was found that the variety Bitambi produced seed and consequently further observations on mutations were discontinued.

SEED

After the discovery of seed producing plants, in a thirteen acre field of sweet potatoes, it was decided to determine the extent and possible importance of this observation. It was found that most of the seeds were around the perimeter of the field, although seeds were to be found within the field itself, particularly on some Kalebe plants which were included by error in the original planting material. In the sweet potato museum block at Kabanyolo the following varieties were also observed to produce seed :—

1. Chai No. 12
2. Early Port
3. Kanena No. 19
4. Sekolya
5. Introduction No. 53
6. Kwoko No. 13
7. Mulalama No. 31
8. No. 61 Amani 834 E
9. Caroline Lea
10. Bitambi
11. Introduction No. 76
12. Kyebandula
13. Kalebe
14. Magabali
15. Kawungezi
16. Namujuna

The only variety in the museum plots that has not produced seed is Introduction No 46, although varieties Kanena, .Mulalama, No. 61 Amani and Namujuna produced seed only sparingly.

Flowering sweet potatoes growing in peasant farmers' plots were examined at every opportunity to see if they produced seed. Seed production was observed frequently in peasant cultivators plots growing in Buganda. Flowering sweet potatoes have been examined in Zanzibar, Tanganyika and Kenya, but no seeds have been found. Recently Tribe, (14) working at Serere in the short grass northern part of Uganda, has reported the production of a few seeds on some varieties in old museum blocks.

Sweet potato seeds resemble small morning glory seeds and are produced in capsules containing one to three seeds. There are approximately 18,000 Bitambi seeds to the pound.

PRODUCTION OF SEED AT KABANYOLO

Some observations have been made of the seeding characteristics of the varieties in the Kabanyolo museum plots. Moveable cages of dexion and nylon mosquito netting were constructed which completely covered the individual variety plot The plots inside the cages were sprayed with insecticide at regular intervals.

After a period of observation to see that no natural seed setting occurred in the variety in the cage, the variety was selfed Production of seed by selfing was found to occur in the varieties Bitambi and Magabali.

Although the characteristic of self fertility is definite, care must be taken in assuming that the other varieties are not self-fertile. Experience with Bitambi indicated that one may have a run of unsuccessful 'sets' of pollinations before one is successful. For example, of the fifteen 'sets' of self pollinations the first three 'sets' produced no seed and of the next twelve 'sets' a further three set no seed. A 'set' of pollinations was made up of between ten to twenty five individual flowers, being more or less the total production of flowers in the cage which were all pollinated at the same time on the same day. Further selfing studies are necessary before the other varieties can be difinitely stated to be self sterile.

Details of the cross pollinations carried out at Kabanyolo are shown in Table I. Each variety was first tested for self fertility and when it was found to be self sterile then crossings were carried out. Work on Bitambi and Magabali indicate that more detailed work will be required before it can definitely be stated that any variety is in fact self sterile, and as the crossings were done without emasculation then the chance of some selfing occurring cannot be ignored, particularly with the varieties Bitambi and Magabali. Of the 191 Bitambi flowers selfed in seventeen 'sets' only 39 set seed i.e. 20% successful compared to 32% for the 'crossed' successes; whether this is a significant difference cannot be determined unless further studies are initiated.

Observation at Kabanyolo shows that unfertilized flowers fall off from five to ten days after pollination.

There would seem to be a suggestion that the older plants produce seed more readily e.g. the museum plots at Kabanyolo have been grown continuously on the same land for six years.

Almost all the flowers of the varieties in the Kabanyolo area are more or less homostylic and only one variety, Caroline Lea, was found to be pin-heterostylic (no anther level with the stigma).

NATURAL SEEDLINGS

Observations were made to see if naturally produced seed germinated in the field. On the Kabanyolo Farm it was possible to find sweet potato seeds that had germinated to the two cotyledon stage, but usually they were smothered by the parent plant and died. For a long period no established seedlings were found, until 1963 when about one hundred vigorous seedlings were found growing in a field in which sweet potatoes had just been harvested. No established seedlings have been observed on plots outside Kabanyolo, although mature plants that may have arisen from seed have been seen.

GERMINATION

No difficulty has been experienced in germinating fresh sweet potato seeds, but if the seed is old and well dried chipping of the seed coat is necessary. At Kabanyolo chipping was done with a scalpel or razor blade and one 'nick' was made per seed. The seeds were then soaked over night on very wet blotting paper and those that had imbibed water were planted into compressed peat pots. Germination was usually between 60-80%.

DETERIORATION OF VARIETIES

That deterioration occurs within cultivated varieties is a generally held belief, but it is difficult to prove. It would also seem that the deterioration is associated with a virus or virus diseases. In 1957 Sheffield (10, 11) reported that two viruses, attacking sweet potatoes in East Africa, had been identified. Virus A is transmitted by aphids and is a mild disease. Virus B is transmitted by white flies, is widespread and exists in several strains some of which cause severe diseases. Hansford (4) stated that "the symptoms vary widely with the host variety". In another paper (9) Sheffield reported than "in some cases no obvious stunting is shown, the symptoms being confined to mottling, or one runner only may be affected or one branch only of one runner. It is probable that the stunted forms are primary infections (i.e. they arose from infected vines), the milder forms being secondary (or new) infections". Aldrich (1) suggested that the virus problem is major in any work on sweet potatoes; he found that in his husbandry experiments, the error was greatly increased due to virus attack. Aldrich also stated that a plant showing severe virus symptoms yielded only 33% of the crop obtained from a virus free plant. Moderate and light infections resulted in yields of 50% and 95% respectively. Gooding (3) also suggests that there has been "widespread degeneration of clones as a result of virus infection" in Trinidad.

In a later report (12) Sheffield refers to suspected internal cork material from Uganda and reported (a) failure to transmit the disease and (b) that non-transmissable abnormalities similar to those seen in Uganda (material ex-Kabanyolo) occur in Louisiana, but their cause is unknown.

The position regarding virus disease and its effect on yields is confused due to several factors such as differences due to altitude effects (8), variation in symptoms between varieties and variation in symptoms on one variety.

The deterioration picture in Uganda is even more confused due to the fact that the peasant cultivators seem to have sources of new varieties, which, if it is similar to an old variety, they then name as the old variety with the prefix "new". For example on farms around the Kabanyolo Farm boundary there are to be found the following varieties:— New Bitambi, New Kawungezi and New Narmujuna. This could suggest the occurrence of bud mutations, as has been inferred by Gooding (3) in the West Indies, but the writer is not of this opinion. On one occasion a visiting party of women, who are the main cultivators of household plots of sweet potatoes, were taken to see a plot of 96 sweet potato seedlings growing at Kabanyolo and on observing them they gave names to about fourteen of the plants in spite of the fact that the plants were seedlings and thus genetically distinct.

Presumably if the new variety is better than the old variety it will replace it and the prefix 'new' will be dropped by the cultivators after a period of time. This must then cast doubt on the length of time that any one variety has been in cultivation.

It is of interest to note the results of two surveys that have been carried out on peasant holdings adjoining the Kabanyolo Farm boundary to determine the names of the varieties being grown locally. The varieties are:—

Surveyed	29.11.65	9.3.62
1	Kyebandula*	Kyebandula*
2.	Bupenge	Bumpenge
3	Kalingu	Kalingu

4.	Mukutula*	Mukutula*
5.	Bitambi	Bitambi
6.	New Kawungezi*	New Kawungezi*
7.	Kalebe	Kalebe
8.	Ntudebuleko	Ntudde Buleko
9	Gavana	Gavana
10.	Nyindo-za-mulalu	Nyindo-zabalaalo
11.	New Namujuna*	New Namujuna*
12.	Kifuku	Kituku
13	Kashoga*	Kasoga*
14.	Stephen	Stephen
15.	New Bitambi	New Bitambi
16.	Namwezigumu	Namwezigumu
17	Sifumbanga najaba	Sifumba nangajuba
18.	Musanyusa meza*	Katumba
19.	Kitikya mbazi*	Kayulu
20.	Nkajega)	Kyasa
21.	Kojemundege) Ex	Mikaylrl
22.	Mpakatebo) Rwanda	Bukasi-Bunzize
23.	Ntungaboro)	New Kalebe
24.	Ntumbwe	Gafa e Congo
25.	Kiwoko*	

* Similar to those recorded by Nye (7).

SWEET POTATO BREEDING POTENTIAL

The growing of sweet potato seedlings and their variability is described in a paper by the writer (5). The experience gained in growing some 558 seedlings, of which 325 were further propagated vegetatively, indicates that the Ugandan sweet potato seed has very great variability over a range of characteristics and that the breeding potential is high. Not included in the paper, referred to above, is the fact that eight new varieties (final selections), which have been raised from seed and selected for their desirable characters, are now showing signs of having little resistance to virus attack. In a variety trial of the eight selections, plus the control variety Bitambi, the plots were scored just before harvest for the number of plants showing conventional virus attack symptoms. The best variety was the control Bitambi, with over 75% clean plants. The nearest 'raised from seed variety' had only just over 50% clean plants and the worst 10% clean plants. The differences between the control variety Bitambi and the 'raised from seed varieties were significant at the 1% level. No explanation is offered for the fact that the virus attack in the Bitambi plots was very much higher than normally observed on the farm fields.

The over-riding importance of virus resistance was not initially appreciated and the selected varieties were not originally screened for virus resistance; this is an aspect requiring more attention in any future breeding scheme.

From the writer's observations, it would seem that there is considerable variation in virus resistance, both between 'mother' groups and individuals; for example seedlings with Bitambi as the mother plant appear to have more resistance than those from Caroline Lea mother plants, and Early Port mother plant seedlings appear to be very susceptible to virus diseases. Presumably the varieties in local cultivation have been unconsciously selected by the cultivators themselves for virus resistance.

A PROPOSED BREEDING PROGRAMME FOR SWEET POTATOES IN UGANDA

The writer's experience to date is the basis of the following proposed breeding programme for sweet potatoes in Uganda.

It is possible that there are as many sweet potato varieties in Uganda as banana varieties. This fact tends to question the need for breeding work on sweet potatoes, straightforward variety trials being more appropriate and cheaper. However, there has been concern expressed at the rate of deterioration of existing varieties; it is not known whether varieties are deteriorating at a quicker rate these days, but as the virus is of relatively recent introduction it is possible that its effects are becoming more evident. If this is correct then a breeding programme is the only way of producing resistant or immune varieties, although screening of existing varieties should also be done. Further argument in favour of a breeding programme is that the full genetic potential of the sweet potato species cannot be obtained by casual and unconscious selection by peasant cultivators; a considered breeding programme should be a means of considerable improvement. Observations of the sweet potatoes for sale in local markets e.g. Kigezi in the S.E. of Uganda, where many of the varieties for sale were deeply ridged and misshapen also indicates a need for a controlled breeding programme.

Genetically the sweet potato plant is not a very convenient plant to work with, being a hexaploid (2n = 90), but it has the advantage that it has not been exposed to very much selection pressure due to its method of propagation.

Although seed can be obtained by controlled selfing or crossing it is not a very prolific means of producing seed and under such circumstances, it is recommended that the major source of seed should be from open pollinated mother plants. However, as shown by the writer in a paper (5), certain characteristics of the mother plants do appear to be dominant and a controlled crossing programme should be carried out and the parents tested for good combining characteristics

It is suggested that a breeding programme should be based on a population of 3-5000 seedlings per year. This number is based on the availability of seed and is not overlarge.

Large populations will be required in order to allow all the desired characteristics to be combined:—

1. Virus resistence
2. Disease resistance
3. Cylas resistance
4. Palatability
5. Total yield
6. Tuber shape and size
7. Skin colour
8. Depth at which tuber is produced

9. Maturation period
10. Vine production (for propagation purposes)
11. Rooting at the node capacity (for propagation purposes).

All seedlings would be raised in the 'egg container' type of fibrous pots until the five to seven leaf stage when the roots begin to penetrate the sides of the pots (3 to 5 weeks approximately). Then the seedlings and the fibrous pots are to be planted out on ridges at a spacing of 3' x 2'. As soon as the seedlings are large enough three cuttings are to be obtained from each seedling and these are to be planted on three mounds at a spacing of 3' x 3'. Previous work at Kabanyolo has shown that there is little correlation between the seedling's tuber characteristics and those of its vegetative progeny and thus selection at the seedling stage is unwise.

At this stage the individual plants will have to be exposed to virus carrying vectors.

On maturation of the sweet potatoes at five to five and a half months all plants showing virus symptoms will be discarded, plus all plants that have other undesirable characteristics e.g. lack of tubers, mis-shaped tubers, lack of vine vigour, other disease susceptibility etc.

The survivors (less than 20%) will be replanted on a further three or more mounds and observed for virus symptoms. (There appears to be a difference between plants with a primary or a secondary infection and consequently one has to go through two generations before the plant's resistance can be determined). Surviving plants will then be bulked up and put into variety trials.

Virus resistant or immune plants (if produced) would be kept even though their other characteristics were not favourable, and used in a crossing and selfing programme.

SUMMARY

Although the sweet potato crop is relatively important as a food crop in Uganda (586,000 acres in 1963) it has had little research attention. Recent observations of significance have been (1) the recording of the presence of sweet potato virus diseases in Uganda by Hansford in 1944 and (2) the observation (by the author) of reasonably prolific sweet potato seed production in 1961. That deterioration of sweet potato varieties occurs is generally accepted, but no field surveys have been carried out to assess the importance or rate of the deterioration; the position is complicated by the peasant cultivator assigning existing variety names to new varieties, which may conceal a greater deterioration rate than is apparent.

From preliminary observations on the variation exhibited by sweet potato seedlings (5), the breeding potential of the Buganda seed is good. However, an error in breeding procedure was made by the author, in that there was no screening for virus resistance at an early stage in the programme. Consequently the Kabanyolo sweet potato seedling selections, which appeared to have combinations of the desired characteristics, have had to be discarded due to their virus disease susceptibility. The writer has proposed a breeding programme, based on the

Kabanyolo experience, which should correct this basic error in procedure. Visual observation on the existing cultivated varieties, individual seedlings and seedling 'mother' groups indicate that there is a range of virus resistance which can be exploited, quite apart from other improvements.

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Table 1.

	Variety (Female)	No of sets of pollinations (1)	No of sets producing seed (2)	Varieties (male) with which cross fertilization occurred
1.	Caroline Lea	11 (78)	7 (36)	Namujuna, Bitambi, Kawungezi, Kanena, Early Port, Magabali.
2.	Namujuna	4 (70)	Nil	
3.	Kalebe	4 (100)	1 (1)	Bitambi.
4.	Bitambi	11 (104)	6 (33)	Caroline Lea, Kawungezi, Kiwoko, Mulalama, Early Port, Magabali.
5.	Kawungezi	5 (52)	1 (5)	Caroline Lea.
6.	Mulalama	4 (64)	1 (1)	Early Port.
7.	No. 46	1 (20)	Nil	
8.	Early Port	7 (70)	3 (19)	Caroline Lea, Kawungezi, Kiwoko.
9.	Magabali	6 (89)	8 (41)	Caroline Lea, Namujuna, Bitambi, Kawungezi, Mulalama, Kanena, Early Port, Kiwoko.
10.	Chai	5 (50)	5 (25)	Caroline Lea, Namujuna, Bitambi, Malalama, Early Port.
11.	Secolya	5 (48)	Nil	
12.	Kiwoko	8 (80)	Nil	

(1) The figure in brackets is the total number of flowers pollinated.

(2) The figure in brackets is the total number of seeds produced.

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DISCUSSION 5

Mr. Williams :

I have two questions to put to the speakers. The first is addressed to Dr. Leon and the second to Dr. MacDonald. I need to make a few prefatory remarks to the question I want to put to Dr. Leon. You have made reference in your paper to the wide variation you encounter in the tuber size and colouration within single plants of yuca. Did I understand you correctly ?

Dr. Leon :

I referred to the variation, in particular, in colour in some of these Andean tubers.

Mr. Williams :

Within single plants ?

Dr. Leon :

Yes.

Mr. Williams :

Dr W B Storey from the University of California, Riverside, found that endo-polyploidy in roots in a number of species and also chromosome reduction and somatic chromosome reduction, and elimination in some other plant species, such as certain members of the cycadales was associated with root morphogenesis. I would like to say as well, that Dr. Storey and I did some examination on somatic cells, and found the same suggestion in tannias, that in the Xanthosoma species, in I. trichocarpa, I. gracilis, and sweet potato, I did some somatic examination and found this suggestion— endopoliploidy might be connected with the differentiation of roots, particularly with respect to the cells which are involved with the storage of starch and so on.

In the Xanthosoma there are very large giant cells, in which can be found raphides, piles and piles of raphides. Do you have any evidence in this crop, the yuca, that this phenomenon might be implicated ?

Dr. Leon :

No. I do not have any evidence but the oxalis is a high polyploid. It is a very complex group of high polyploids concerned in the yuca and the cultivated oxalis is the highest polyploid in the genus.

Mr. Williams :

Mr. MacDonald, I would like to enquire whether you consider that the absence of seed set in many of your varieties in Uganda could be connected with the possibility that most of your cultivars may belong to the same intra-incompatible group, or in other words, that there may be a few intra-compatible groups in Uganda sweet potato cultivars.

Mr. MacDonald :

We have not looked into this aspect but the seed set amongst the varieties in Uganda is in actual fact quite good. I have no standards of comparison to go on. I can go into a 12 acre field of Bitambi and collect without difficulty something of the order of 5000 seeds, which are open-pollinated. Within the 18 varieties that we have in the museum, we have done some crossing. Admittedly some of the varieties do not cross particularly well — you may get one or two seeds, but the vast majority of them will cross quite easily. Caroline Lee as I remember was giving us 50% set in crosses. This seems quite reasonable to me. In other words of 76 flowers pollinated we could expect to get 38 capsules. Normally we only get one to two seeds per capsule, rarely three.

Mr. Williams :

I was motivated to ask the question, particularly with reference to your local variety, because there is the possibility that if this is true, there may be a few intra-incompatible inter-compatible groups in your sweet potatoes which could relate to the pattern, the history of introduction of the species, in other parts of the world.

Dr. Rogers :

Dr Leon, in relation to the species Tropaeolum, the one that grew at about four or five thousand metres, what is the relationship of this species to the lowland species of Tropaeolum in Peru ?

Dr. Leon :

There is no relation. Apparently, this species is not found wild any more. At the lowland elevation they grow lots of Tropaeolum which are used as vegetables. The leaves are harvested, and are sold in the market, but not in this particular species that grow at the higher elevations.

Dr. Rogers :

Are there evidences, ethnological or archaeological, about the age of this Tropaeolum at the high elevations ?

Dr. Leon :

There is no evidence from the ethnological or archaeological point of view.

Dr. Bolhuis :

Are these short day or long day plants ?

Dr. Leon :

Most of the plants are short day plants, but we have some which are practically indifferent to length of day.

Dr. Jones :

Dr. Leon, what is the potential economic range for these highland tubers around the world ? How far will they grow in the temperate zone, and where might they grow in the tropics ?

Dr. Leon :

They have been tried in several places. For instance, once in a while you find Ocas in the Paris market in France, and they have been grown in southern France for a while, and they were tried in England. And the famous, Vilmorin wrote several papers in the introduction of yucas. As Dr. Bolhuis mentioned, most of them are short day plants, so they will not grow very well because they need plenty of sunlight and short days, so it is very difficult to grow them in temperate zones.

Arracachas on the other hand have been grown in many places outside the Americas, and also in the temperate zone, for instance, in Sao Paulo in Brazil where Arracacha is a commercial crop for the preparation of soups and so on in canned and dried material. I would like to mention also, that there is one other tuber in the Andes — they call it Jacon — of the Compositae similar to Jerusalem artichoke, and this has been tried also in Europe as a source of inulin because the tuber has inulin-like properties and has been tried commercially without much success. But it has been grown for years for that purpose in southern France and Italy.

Dr Maner :

Dr. Leon, you made some comments concerning the nutritive value of some of the root crops that you have studied. You stated that some of them were very high in protein and had very good amino acid content. Are these data available, if so, where ?

Dr. Leon :

This is a little confusing, this data of solbe. These root crops are poor in food value, in general, but once they are frozen and dried, then the protein content climbs to 8%. What I mentioned is that quinoa (a cereal used as a complementary food with highland Andean tubers) is an excellent source of protein and Dr. Bolhuis has done some work on this in Holland. He has published a paper on the subject.

YIELD TRIALS WITH *DIOSCOREA ALATA*

—*by*—

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Yams, Dioscorea species, are grown throughout the Caribbean area and are of varying importance in various territories. The collection and preliminary observation of nearly a hundred clones by H. J. Gooding indicated that there was an urgent need for reliable information on a number of characters of these yams, especially yield.

With this in view trials have been carried out over the last three years and this paper presents some of the results.

Although we have not yet obtained any seed of *D. alata,* and it may prove difficult to do so, a number of freely seeding clones of *D. trifida* are in our possession. It was also hoped therefore that a knowledge of character variations and their inter-relationships would be of use in the execution of future breeding programmes in *Dioscorea.*

MATERIALS AND METHODS

Materials

The materials used in these trials are six of the cultivars of the yam *Dioscorea alata* collected by H. J. Gooding throughout the West Indian region between 1957 and 1960. During the period 1960 to 1963, the 98 cultivars of *Dioscorea* collected were put through preliminary observation, selection and multiplication, by H. J. Gooding here at St. Augustine.

The cultivars under trial were all of the Lisbon group of *Dioscorea alata* and appear to be very closely related although each is a recognizably different clone. The names obtained at the time of collection and their accession numbers and their place of origin are listed below :

Name	*Accession No.*	*Place of Origin*
Ashmore	03/59	Grenada
Barbados	14/57	St. Vincent
Harper	01/59	Barbados
Oriental	39/57	Barbados
Seal Top	33/60	St. Croix
Smooth Statia	02/60	Dominica

Methods

In all trials four ounce sections of tuber were used as planting material and these were planted at 18-inch intervals along ridges three feet apart. All the trials were laid down in randomised blocks.

In 1964, the trial was planted on the 2nd of June, weeded by hand on the 15th of July and staked with bamboo poles on the 16th of July. The trial was first sprayed by mistblower with Cupravit at a concentration of one ounce per gallon on the 8th of September, and at fortnightly intervals thereafter, until the foliage was dry. The trial was reaped by hand and the records taken in the field on the 25th, 26th, 27th and 30th of November, and the 1st and 2nd of December.

In 1965, the trial was planted on the 14th day of June, and staked with wire and string on the 22nd of June. Spraying in the manner described for 1964 was started on the 15th day of July. Weed control was effected with Gramoxone and the trial was reaped on 14th December.

In 1966 the trial was planted on the 17th of May and staked on the 27th of June with wire and string. Spraying alternately with one ounce per gallon of Cupravit and half ounce per gallon of Zineb was carried out at weekly intervals starting on the 12th of July. Weeds were controlled with gramoxone and the trial was reaped on the 10th of January.

No fertilizers were applied to any of the trials and they were carried out at different points on the University Field Station at Champs Fleurs in Trinidad.

The variation in planting date is due to variation in the onset of the rainy season and in the sprouting of the yams. Reaping was carried out when all the foliage was dry and it is assumed that all cultivars are fully mature. The late reaping in 1966 may be attributed to better disease control and a late and wet dry season.

In 1964, eight replications of thirteen-eight-plant block and in 1965 five replications of thirteen-four-plant blocks, and in 1966 four replications of thirteen-four-plant blocks were planted.

A plant which had produced a tuber was recorded as having survived regardless of how small the tuber may have been. This was found to be necessary since records were taken after all the foliage had been removed along with the stakes or staking material to facilitate the accurate recording of individual plants.

Weights were recorded to the nearest quarter ounce and the tubers from all the surviving plants in a block were weighed together. There are therefore some instances where a plant is recorded as being present, but no weight of tubers is recorded.

A guard row of plants was planted around each replication and an extra guard row was planted on both windward sides of the whole experiment to minimise the effect of buffeting and premature drying out by the wind.

Wherever statistical significance is stated as being present and the level of probability is not stated it is the 0.1 per cent level which exists.

RESULTS

Table I gives the means of the percentage stand at reaping, the yield in long tons per acre and in ounces per plant for the three years 1964, 1965 and 1966.

It may be seen that both survival and yield were depressed in 1965, the year in which there was an early and severe attack of a foliar disease caused by *Colletotrichum*. In 1964 the disease built up much later in the growing period and was less severe in that it did not destroy the trials completely, the cultivar Oriental seeming to be the least affected. This may be due to this being the second year in which yams were grown on a reasonably large scale for some years. Yield in this year is on average midway between the yields in 1965 and 1966 while survival is approximately equal to that of 1966. In 1966, a greater knowledge of effective control measures and earlier and more intensified spraying effected considerable control of the disease and the yields are considerably higher. The variation between years in yields and survival may therefore be due mainly to differences in the intensity of disease attack.

It should be noted that the halving of the 1964 mean yield over all cultivars in 1965 and its doubling in 1966 are accompanied by only a 15 per cent reduction in survival and no significant change respectively.

Thus, even with a disease which often kills the entire crop, yield may be severely affected without affecting survival.

In 1964 and 1966 the yield of the cultivar Oriental was two to three and a half times higher respectively than Seal Top, the highest yielding of the other cultivars. The differences are statistically significant at the 0.1 per cent level of probability. In 1965, however, all cultivars were reduced to approximately the same level of yield presumably by the severe disease attack, and only the difference between the cultivar Ashmore and Oriental is statistically significant at the 5 per cent level.

This high yield in the cultivar Oriental is linked with a stand of 95 and 96 per cent at reaping which may be regarded as very close to the maximum attainable under field conditions. Although this survival is at least 20 per cent higher than any other cultivar it cannot entirely account for the greater yield.

Table II gives the coefficient of variation between plants and between replications and the degrees of freedom for the number of surviving plants and yield. Comparison of the coefficients of variation between plants for both parameters with the means for the corresponding parameters in table I shows that there is generally an inverse relationship both between cultivars and years. This is not surprising since variation tends to increase proportionally with the level of stress and yield may be expected to have an inverse relationship with stress. If yield is only limited by genetic potential then this argument does not hold, however, the presence of disease at various levels of intensity suggest that this is not the case

In some years, in some cultivars the coefficients of variation are below or in the region of 40 per cent. This is sometimes regarded as an acceptable level of variation for field trials under tropical conditions. Thus, with care in the choice of cultivar and disease control, trials on other aspects may have few problems of a statistical nature.

The coefficients of variation between replications show relatively haphazard variation. Generally the years and cultivars with the highest yields and survivals show low between replication variances. These very large coefficients of variation are typical of trials where disease plays an important part. This particular disease appears to be spread by rain splashes and the crop is usually destroyed by the progressive extension of the centres of infection. It is probable that the patchy nature of the infections has led to these very high coefficients of variation.

These large variances and their very sporadic variation are reflected in seemingly meaningless series of variance ratios. It can only be suggested that the lack of significantly larger between replication variances in 1964 is mainly due to increased between plant variation and not to decreased overall variability.

Table III gives the coefficients for the correlations between number of surviving plants and yield for all cultivars in all three years.

All the correlation coefficients are statistically significant at the 0.1 per cent level except that for the cultivar Oriental in 1966 where it is significant at the 5 per cent level.

It may be noted that where the percentage survival and the correlated parameter yield are highest, the correlating coefficients are lowest. The converse is also true.

Values of correlation coefficients nearer to a half show a more haphazard relationship. These relationships suggest that other factors have a significant effect on the coefficients and these were either not measured or not measured with sufficient accuracy for the relationship to be clear. However, at the highest and lowest yields and survivals, the extreme nature of these parameters and their variances allows them to have an overriding effect.

Thus, the low and barely significant correlation shown by the cultivar Oriental in 1966 may be mostly due to the very low variance, especially in survival which is very close to being complete.

DISCUSSION

It is very interesting to note the rather wide variation in yield and survival that has been recorded and to speculate on the possible causes and relationships between these and other parameters.

The general question of the relationship between yield, survival and the severity of disease attack can bear discussion. In every cultivar except Barbados, there were large and statistically significant reductions in yield that were not accompanied by similar reductions in survival. In the lowest yielding cultivars Ashmore, Harper and Smooth Statia, survival is reasonably constant in the two worst years 1964 and 1965, yield, however, is much lower in 1965. In the higher yielding cultivars Seal Top and Oriental, the very severe disease attack in 1965 reduces both survival and yield when compared with 1964, but the far more effective control of the disease in 1966 does not allow a survival significantly above that in 1964 although it allows a statistically significantly higher yield.

Bearing in mind that a plant is recorded as having survived if at least one tuber of any size is produced, variation in the date of tuber initiation may be the most important factor affecting survival in the presence of a foliar disease which usually builds up after a significant amount of foliage has appeared. Thus it would be very interesting to determine whether the three cultivars which do not show differences in survival under medium or severe disease attack initiate tubers early before the onset of the disease and thus meet the conditions for survival without necessarily having any real resistance to the disease.

Yield would thus be the character which would indicate resistance or tolerance, since tuber bulking should be curtailed in proportion to the severity of disease attack.

It will be recalled that all trials were reaped at full maturity of all cultivars. Thus, the extent of the period over which tubers are bulked may easily be the most important factor determining overall yield. This is not a novel suggestion and it would explain the low and similar yield of all cultivars in 1965 when the growing season was severely curtailed by disease. The similarity is particularly apparent in the number of ounces produced per surviving plant since survival is no longer a complicating factor. It would also explain the higher yield in 1966 given by Oriental and Seal Top at similar survivals to those shown in 1964.

It would be similarly interesting to determine whether the duration of tuber bulking is the same in all cultivars, and the factor which determines yield is the timing of tuber initiation. It may be that low yielding cultivars initiate tubers early when there is less foliage available for starch production, and the foliage dies back and bulking stops without ever having attained its full physiological potential. In high yielding cultivars, tubers may be initiated late and bulking may be far more rapid and thus more extensive in the same period, because of the more developed foliage. The early tuberizing low yielding cultivars would, however, have the advantage in survival under conditions of severe disease attack, and this may account for their continued existence.

The answering of these questions may well provide fruitful fields for future research and they would no doubt be as informative as they have been in other crops. They should also be of invaluable assistance to the planning of breeding programmes in this genus.

SUMMARY

Trials over three years of six cultivars of the yam *Dioscorea alata* are described. Differences in the severity of disease attacks are suggested as a main cause of variation in yield in different years. The significantly high yielding cultivar Oriental shows no greater yields under severe disease attack.

Table I

	Percentage Survival				Yield in long tons per acre				Yield in ounces per surviving plant			
	1964 Mean	1965 Mean	1966 Mean	Overall Mean	1964 Mean	1965 Mean	1966 Mean	Overall Mean	1964 Mean	1965 Mean	1966 Mean	Overall Mean
Ashmore	55	52	63	57	1.23	0.83	3.53	1.86	8.3	5.9	20.8	11.7
Barbados	67	56	78	67	1.79	1.24	4.97	2.67	9.9	8.2	23.8	14.0
Harper	77	79	52	69	2.04	1.28	1.46	1.59	9.9	6.0	10.5	8.8
Oriental	95	64	96	85	7.55	1.29	11.21	6.68	29.6	7.5	43.4	26.8
Seal Top	68	55	69	64	2.21	1.13	5.28	2.87	12.1	7.6	28.3	16.0
Smooth Statia	58	56	68	61	1.52	1.08	3.85	2.15	9.7	7.1	20.3	14.7
MEAN	70	60	71	67	2.72	1.14	5.05	2.97	13.3	7.1	24.5	15.3

NOTE: 1 long ton per acre equals approximately 2.5 metric tons per hectare.

Table II.

	Number of Plants						Yield					
	Coefficient of Variation						Coefficients of Variation					
	Between Plants			Between Reps.			Between Plants			Between Reps.		
	1964	1965	1966	1964	1965	1966	1964	1965	1966	1964	1965	1966
Ashmore	40	63	43	53	61	63	72	113	58	169	67	201
Barbados	28	59	25	56	76	45	67	107	49	145	156	138
Harper	26	25	49	41	48	152	70	87	80	190	184	237
Oriental	30	45	13	28	85	7	34	93	36	57	95	58
Seal Top	31	55	40	57	125	78	58	93	63	199	167	167
Smooth Statia	36	63	46	48	65	77	81	140	62	130	109	176

Table III.—Correlation Coefficients.

	1964	1965	1966
Ashmore	0.583	0.740	0.512
Barbados	0.579	0.757	0.618
Harper	0.584	0.429	0.773
Oriental	0.387	0.642	0.288*
Seal Top	0.602	0.658	0.632

*All coefficients are significant at the 0.1 per cent level except that for Oriental in 1966 which is significant at the 5 per cent level.

DISCUSSION 6

Dr. Martin :

I would like to ask Dr. Royes what has become of the collection of the **D. alata** cultivars ? Is it still in tact and do you have any plans to do anything further with it ?

Dr. Royes :

You will see all of them tomorrow afternoon in the field.

Dr. Yen :

Mr. Chairman, I would just like to ask Dr. Royes about his concept of tuberisation. While he has made quite a strong case about selection against — I think he called it 'Mother Nature' — in that the tuberisation process goes on for some considerable time, I wonder whether this is really valid. I think also, we ought to look at the distribution of the plants in a pan-tropic way.

D. alata, the greater yam, is really one of the basic crop plants of agriculture in many parts of the Pacific. In the types of agricultural systems that are there, the swamp people of Southern island of what was Dutch New Guinea are forced to phase their agricultural operation with the seasons. One of the plants identified as **D. aculeata** (I suggest it to be **D. esculenta**) and the other one is **D. alata**. Now this has to be harvested in reasonable time because when the floods come its impossible to cultivate any more. Now you might say well they are satisfied with very low yield but I do not think this is the case. If you see the photographs in Serpenti's 'Cultivators of the Swamps' you will see some large tubers. I wonder, then, whether it is justified to call 'chicken' at this stage.

Mr. Gooding :

I would like to make one or two comments on Dr. Royes' paper. First of all I noticed the yields obtained in Trinidad are rather on the low side. The average yield for yam in Barbados is about 5 tons and if you do not get up in the 6 or 7 tons you are not really in business. I was rather surprised to see yields running around 2 and 3 tons on the average especially in Trinidad where it is the custom to stake yams and everybody coming from Trinidad tells us in Barbados that you ought to stake yams — we do not stake them — and we will get much higher yields. Survival at 85% is again a normal thing in our commercial plantations. We don't get these big losses except on rather rare occasions when we do have severe attacks of **Colletotricum**. This has only been noticed by planters in recent years. We find that if we spot it in time we can spray the field down with a copper fungicide and usually control it. Regarding the initiation of tuberisation I would like to comment on that. I will be mentioning this in my paper on Wednesday so I'll let is pass at the moment.

But another point. I think somewhere along the line Dr. Royes mentioned about the leaf area of yams. We have in fact measured this on commercial plantations. We have measured single plants lying on the ground not staked with leaf area totalling about 75 sq. feet, 800 leaves and upwards per plant and total stem lengths measuring a total length of 400 feet. A single yam plant of **D. alata** can be a very considerable plant indeed and we have measured tubers weighing up to twenty pounds but we do not like them at that size but just as a matter of interest for the meeting this is the kind of thing that does happen even in commercial practice.

Dr. Royes :

I just mentioned — well we have made it a practice of trying not to complicate any of these varietal trials with any other factors. We invariably got hammered with disease and yields were all low. We do not fertilize or anything of this nature and when you see the soil at the Field Station you will know what we are up against. The second case is that Barbados is a far drier island. If the diseases get hold of cultivation then do not waste your money on sprays.

Dr. Coursey :

The simple sore points I would like to mention on Dr. Royes' paper are first of all the question of leaf area index or leaf area whether there may be gain or loss of foliage. Some experiments on pruning of **D. rotundata** were carried out in Nigeria some years ago. As far as I know they were not recorded anywhere but I did see the rough results which indicated that removal of foliage tended to diminish yield. There was no advantage whatsoever in pruning. Now I would like to discuss very briefly a point in connection with **D. alata**. It is of course Asiatic in origin and the number of cultivars existing in Asia, Indonesia and the Pacific is far greater than the number existing in the Caribbean. When we consider the history of **D. alata** in the Caribbean we must remember that it came here in slave ships. The planting material which was first introduced from Asia and then from the Portuguese plantations in Tortomay and West Africa had been selected for their storage quality. You probably have varieties which are very good in storage but may not be so good in other respects. Weight of individual tubers of up to a cwt. can be obtained with some of the Asiatic forms without all that much difficulty. Well perhaps that is a slight exaggeration but without any great difficulty certainly 20 or 30 lbs is in no way exceptional. Similarly of course there are hundreds or I would like to say, thousands of cultivars of **D. rotundata** and **D. cayanensis** in Africa which have never been recorded at all. It thus seems as though there is some potential there which might be better producing than some of the varieties here. Also I just mentioned within the species **D. rotundata** there is enormous variation in time of initiation of tuberisation. There has been no systematic work done on this but one knows from experience that adaptation of the same species to a wide range of dry season ranging from only two or three months in the south to nearly six months in the north.

Dr. Royes :

I hate to seem callous but I have looked upon these trials that I have done as a sort of terminal. I mean we now say that one of the best ones we have now is Oriental. We have not been able to do any breeding as I mentioned, because we do not get any seed except in **D. trifida**. Now we are not short of work and I feel that it may take in the region of ten years to get some reasonable results from breeding as opposed to selection in **D. alata**. I think we are going to try with **D. trifida** because personally I would much rather eat **D. trifida** than **D. alata** and I think West Indians are very fussy people and they are not going to eat **D. alata** if they can get **D. trifida**, so we may as well not breed it.

Dr. Coursey :

I'll just come back for one minute on this. I am very much inclined to agree with Dr. Royes on this point about **D. trifida**, but this does seem a point to mention— that there is a great need for plant breeding work to be done on any sort of yam. Whether this is the appropriate place to do it I can't say but somebody ought to be doing some and nobody else is.

Dr. Martin :

I would like to make a few comments on the breeding aspects of yams. It is true that this is one of the tropical root crops that has been neglected and there are some very good reasons for it. Most of the cultivars of the cultivated yams, with the exception of **D. trifida** are polyploid series with very large ranges in chromosome number. In addition, it is very hard to get them to come into flower and when you get them to flower it is hard to cross them. So of all the crops discussed today this is one of the most difficult to breed by conventional methods. On the other hand, there are so many different cultivars throughout the world and so little is known of them that probably a tremendous amount of progress can be made by these commendable efforts of gathering them into collections and trying them out.

CONTENTS

SOME PHYSIOLOGICAL PRINCIPLES DETERMINING THE YIELD OF ROOT CROPS.

— *by* —

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In this paper, the usual liberties taken by agriculturalists with botanical terminology will be accepted: the term 'root crop' will be used to denote a crop grown for some underground organ irrespective of its morphology. The adjective 'tropical' poses greater restrictions — mainly because most of the intimate aspects of the physiology and ecology of strictly tropical root crops are unknown. During the next decade there will surely be a vast extension of enquiry within this field — particularly concerning the description of responses to the main environmental factors and deeper understanding of the correlated functioning of species such as the sweet potato (*Ipomoea batatas*), cassava (*Manihot esculenta*) and yams (*Dioscorea spp*) In the present context the most useful purpose may be served by examining relevant features of two species which are much more fully documented: one, the (Irish) potato (*Solanum tuberosum*) originated in the tropics, has been rigorously selected for growth in temperate climates, and is now finding its way back into the tropics; but for even mentioning the other, sugar beet (*Beta vulgaris*), the indulgence of the more ardent tropical agriculturalists must be sought.

GENERAL FEATURES OF GROWTH

Three phases of growth may usually be recognized : (i) that of pre-emergence, which involves the establishment of an autotrophic plant from materials stored within the mother organ (tuber or seed); (ii) that in which leaf growth is predominant and (iii) that, overlapping with the preceding, in which growth of the storage organ occurs (Fig. 1). The potato and sugar beet represent two extremes of plasticity in respect of internal control of differentiation. Differentiation of tubers on the distal parts of the diageotropic stolons of the potato depends on a particular internal state of the plant; this state is a function of age and of the environment. Usually, there is appreciable development of stems and leaves before tubers are initiated; once the tubers commence to grow, no further leaves are initiated and the leaf surface senesces rapidly. On the other hand, differentiation of the storage root of the sugar beet is peculiarly insensitive to environmental control. The concentric cambia are initiated at a very early stage of ontogeny in a very wide range of environments and the root and leaves develop more synchronously. Root growth eventually dominates over leaf growth — but never completely, there being only a slow decline of the leaf surface over a long period of time. Here, the leaf area is in excess of that required but in the sub-species mangold, where a higher ratio of root to leaf area has been selected (Watson and Baptiste, 1938) a commercially adequate concentration of sugar has not been achieved. The sweet potato — the only other species for which limited growth data are available — would appear to be intermediate: apparently the root tubers commence to store materials relatively late in ontogeny but they grow slowly and the leaf surface, which may be in excess of requirements, declines slowly. There is possible

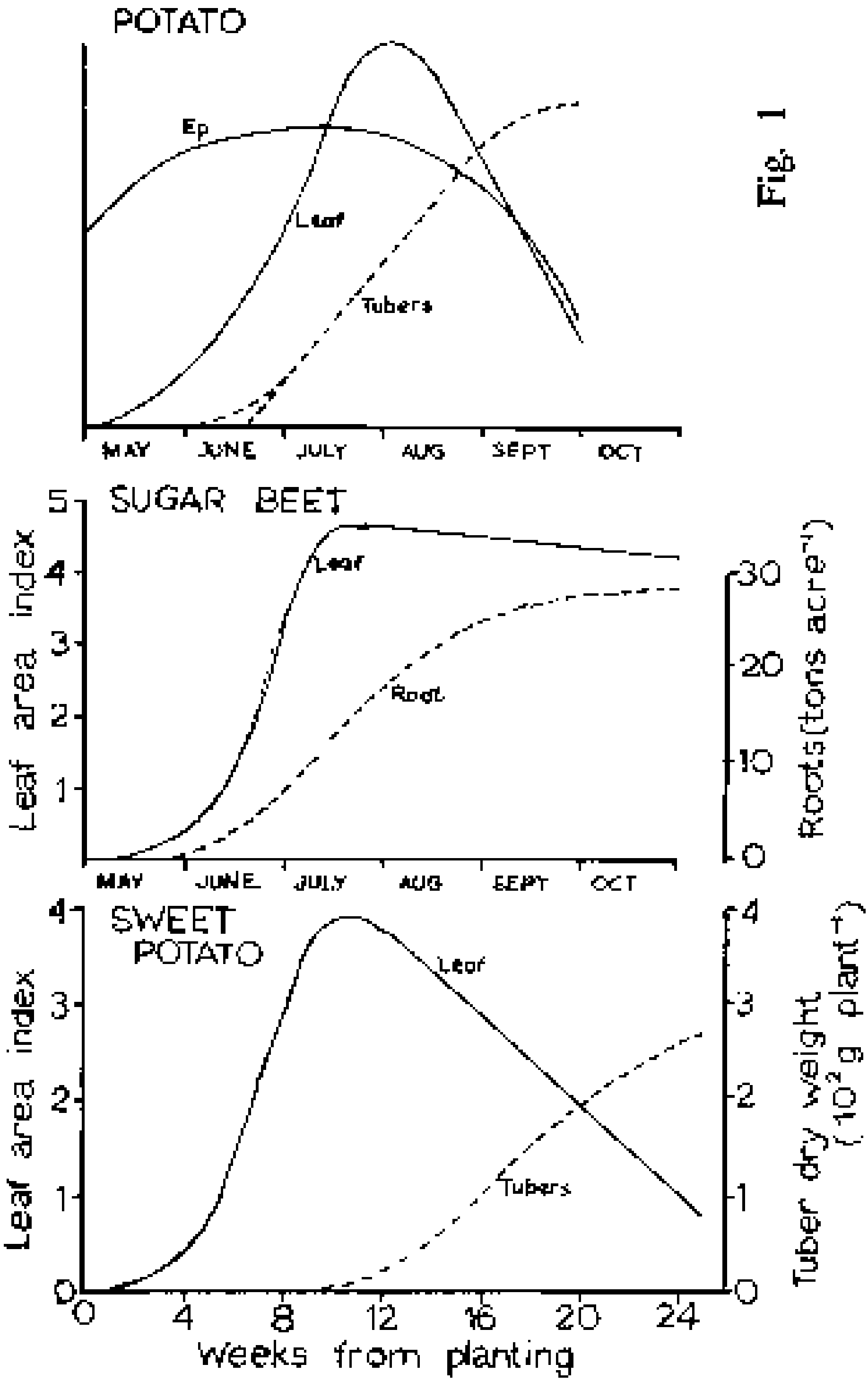

POTATO
Ep
Leaf
Tubers
MAY
JUNE
JULY
AUG
SEPT
OCT
SUGAR BEET
Leaf area index
5
4
3
2
1
Leaf
Root
30
20
10
0
Roots (tons acre⁻¹)
MAY
JUNE
JULY
AUG
SEPT
OCT
SWEET POTATO
Leaf area index
4
3
2
1
0
Leaf
Tubers
4
3
2
1
0
Tuber dry weight (10² g plant⁻¹)
0
4
8
12
16
20
24
Weeks from planting

Fig. 1

scope for selection of varieties with earlier initiation and with a better balance between leaf and root growth than existing varieties.

Agricultural production is primarily concerned with manipulating the responses represented by these curves to achieve certain results within particular environments. The aim may be to obtain the highest yield within the available growing season, as with main-crop potatoes, or to obtain a marketable yield very early, as with first-early potatoes in the United Kingdom. The dominant environmental factor may differ between environments, in Britain and much of Europe low temperatures determine the length of the growing season, whereas in tropical regions shortage of water is often the overriding factor. In Fig. 1, a crude description of the seasonal variation of the adequacy of the environment is given by the potential net assimilation rate; that is, the net assimilation rate of young plants. This probably varies little between species at the same stage of ontogeny whereas growth rates vary much more widely; a more sensitive index would be given by relative growth rates during the one or two weeks following emergence. The curve is smoothed to remove weekly fluctuations; this cloaks the fact that the limits of the season are determined mainly by the probability of occurrence of catastrophic values (from severe frosts or prolonged droughts).

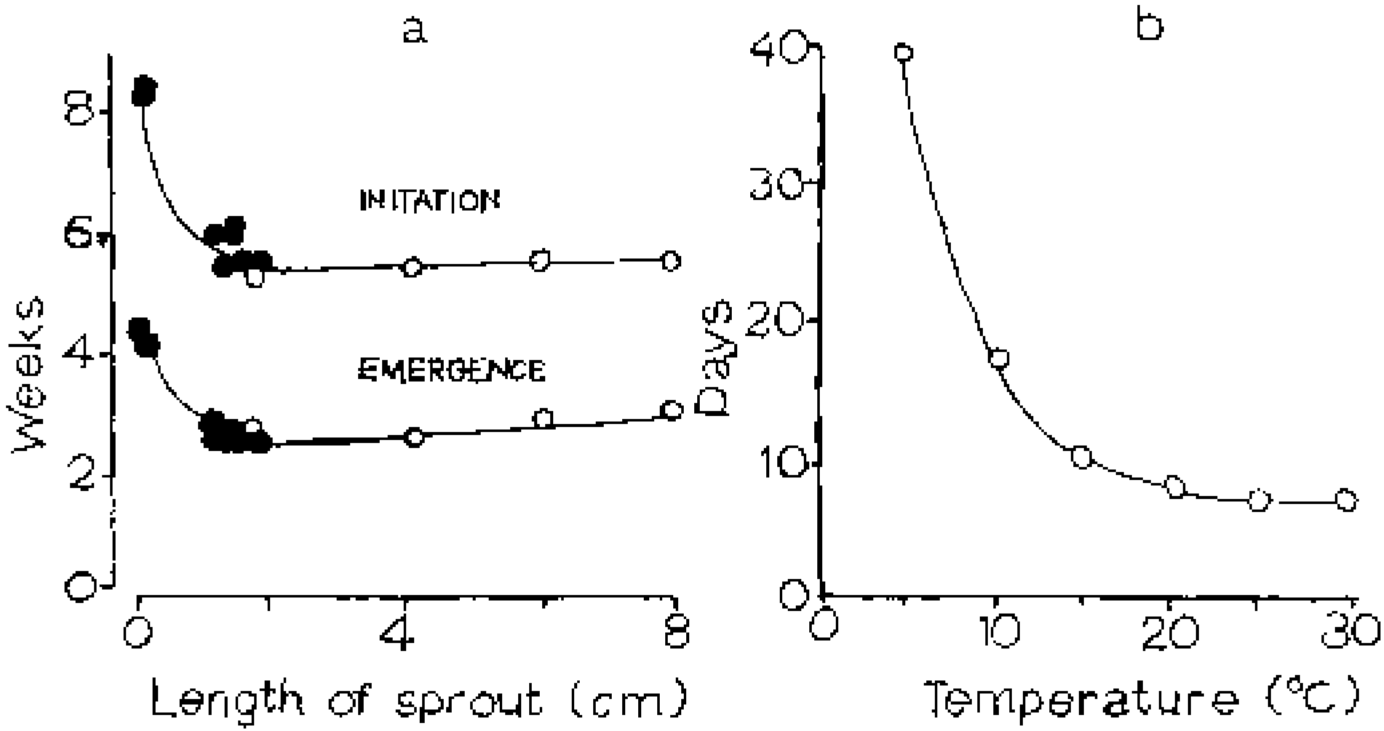
THE PRE-EMERGENCE PHASE

Pre-emergence growth of the potato

The tuber at planting bears a population of dormant, correlatively inhibited and growing sprouts; only those in the last category continue to grow after planting (Morris, 1966a). The mother tuber provides the main source of substrate until the plants have a leaf surface of 200—400 cm^2 (Headford, 1961; White, 1961) although the external supplies of mineral nutrients influences growth at earlier stages than this (Moorby, 1967). Provided there is an adequate supply of water, growth during the pre-emergence phase is controlled by soil temperature and by the degree of development at planting. Generally, the rate of emergence of potato is faster the higher the soil temperature and the greater the degree of development of the sprouts at planting (Fig. 2). Plants grown from tubers with well-developed sprouts also initiate tubers earlier but there is a limit to which these responses can be used in practice. Well-developed sprouts if subjected to low temperatures after planting may initiate tubers before emergence and greatly delay the establishment of the haulm; this is the condition known as 'little potato'. Moreover, proneness to the abnormality known as 'coiled-sprout' is related to the size and degree of development of the sprout (Moorby and McGee, 1966).

There is little advantage to be gained, therefore in planting tuber with sprouts greater than 1—2 cm. In general, the smaller the sprouts at planting the higher will be the yield at natural maturity but the longer is the growing season; sprouts longer than 2 cm give rise to plants which emerge earlier, initiate tubers and give a higher yield early in the season but not at maturity (cf. p 5). The yield and size distribution of tubers is also influenced by the number of sprouts which are growing at the time of planting: the greater the number of these the higher the yield but the proportion in the smaller size grades is also higher (Toosey, 1963).

Fig. 2


a
b
Weeks
8
6
4
2
0
INITATION
EMERGENCE
0
4
8
Length of sprout (cm)
Days
40
30
20
10
0
0
10
20
30
Temperature (°C)

Development of potato sprouts during storage.

The number and size of growing sprouts at planting depends partly on size and variety but mainly on the storage history of the tuber. The many issues involved have been reviewed by Milthorpe and Moorby (1967) and need only be briefly mentioned here. Provided a period of more than three months is available between harvest and planting, the appropriate storage environment can be provided, and the tubers are free of virus and other diseases, conditions during the growth of the mother tubers are of little consequence (Goodwin, *et al.*, 1966). Dormancy, although an intriguing physiological phenomenon possibly involving a balance between gibberellins and inhibitors such as abscisin (cf. Milthorpe and Moorby, 1967), is also of little significance under European conditions of culture. It can, moreover, be readily broken by exposure to gibberellin A3, ethylene chlorhydrin or water (Goodwin, 1966) or prolonged by treatment with nonyl alcohol or other inhibitors (Burton, 1961). The pattern of subsequent growth is, however, of the utmost importance.

The environmental factors exerting the largest effects on growth during storage are light and temperature. There are large differences between darkness and light supplies of about 1 cal cm $^{-2}$ day $^{-1}$; amounts of light greater than this have little further effect. Little or no growth occurs at temperatures less than 5°C. If tubers are stored from harvest at temperatures of 15° — 25°, the apical bud loses dormancy first and starts to grow rapidly. It soon establishes dominance and only 1—2 buds continue growth (Goodwin, 1967; Goodwin and Cansfield, 1967). If, however tubers are stored at temperatures of 7° — 10°, or if dormancy is broken artificially, many buds commence growth. Gradually, the smallest buds are correlatively inhibited and with the passage of time only 2—4 buds will continue to grow. These are direct apical dominance influences in which complex growth-substance interrelationships are involved (Goodwin, *loc. cit.*). The rate of growth also involves mobilization of tuber reserves and competition for these between the growing sprouts; these interrelationships have been discussed by Morris (1966a, 1966b). By using these responses and manipulating the temperature appropriately during storage, the number and size of *growing* sprouts at planting can be varied within certain limits.

Vegetative propagation of other root crops.

Most of the tropical root crops are propagated by stem cuttings but I am not aware of any studies relating to the effect of the source of the cutting on the performance of the subsequent plant. Arguing from the scattered information gleaned from other species and generally presented under the terms "juvenility" and "ageing" — abstractions embodying a general mysticism to cloak our ignorance — it seems likely that time to initiation of storage organs will be increasingly delayed in plants propagated from the following sources: old whole tubers, young whole tubers, main-stem cuttings from plants bearing tubers, main-stem cuttings from young non-tuberizing plants, axillary-branch cuttings. However, variation attributable to differences in previous history of parent material free of disease is usually frequently less than that which can arise from differences in environments during growth (Goodwin, *et al.* 1967).

INITIATION OF STORAGE ORGANS

The potato

The initiation of tubers arises from changes in a number of metabolic reactions occuring at the sites of tuber formation; i.e. in the elongating internodes of the tubers. The actual reactions involved have not yet been explored; studies have been confined to describing the morphological changes, to indirect experiments concerning possible transmissible stimuli and to ascertaining the environmental factors which accelerate tuber initiation.

The first evidence of tuber initiation appears to be that cells of the extending internodes of stolon commence to expand radially rather than continue to elongate (Booth, 1963). This change in the direction of cell extension is soon followed by secondary cell division throughout all tissues (Fig. 3.). The apical meristem continues during some 12 — 14 plastochrons to provide new primary tissue in which extensive secondary division occurs; although secondary division continues in all parts of the tuber over an extended period, continued growth and division appears to depend on the production of new primary tissue from the apical bud. This observation may simply mean that both primary and secondary division are controlled independently by some other factor (such as provision of substrates), but the evidence from studies on second-growth of tubers (Bodlaender, *et al.*, 1964) suggest that soon after the expanding internodes at the tuber apex change from a state of radial expansion to longitudinal extension — i.e. revert to "stolon-type" growth — secondary division ceases in the primary tuber. These data also suggest that the "tuber-forming" state of the terminal bud of a stolon is not permanent or irrevocable but requires the continued maintenance of a certain (unknown) metabolic state.

It would be pleasing within our present superficial knowledge of growth substances to ascribe the non-tuber state to high gibberellin and low abscisin contents and the tuber-forming state to low gibberellins and high abscisin [See Addicott, *et al.*, (1964), Cornforth, *et al.*, (1965) and Thomas, *et al* (1965) concerning abscisin]. A case for this general thesis, with some experimental support, has been made by Booth (1963). One inadequate exploration of gibberellin contents, measured by the Paleg test, showed that apices of non-tuberized stolons, apices of stolons in the earliest stages of tuber initiation and minute tubers contained 1.1×10^{-10}; 2.0×10^{-10} and 2.4×10^{-12} g equivalent GA_3 per apex respectively; if substantiated these results would indicate that tuber initiation is not associated with a marked change in gibberellins but that tuber growth is.

It should be emphasized that it is the changes in the extending internodes of the stolon which must be considered. It is conceivable that a decrease in the ratio of gibberellin to abscisin, say, or changes in balance of other growth regulators, may arise both from differences in rates of production and transport from other organs as well as differences in rates of production *in situ*. The association of tuber initiation with high carbohydrate contents may indicate that sucrose is here the transmitted "stimulus", as suggested by Booth and Milthorpe (1962) — leading to possible changes in balance and concentration of different growth substances localized in the terminal bud of the stolon — or it may mean that in this state less gibberellin and more inhibitors are produced in the foliage and transported to the stolons.

It is well established that tuber initiation is associated with slow growth of the haulm; there is also, in plants of European varieties with similar rates of haulm growth, a rather weak short-day reaction (Slater, 1963). The much stronger short-day reaction in *Solanum andigena* favours the suggestion that growth sub-

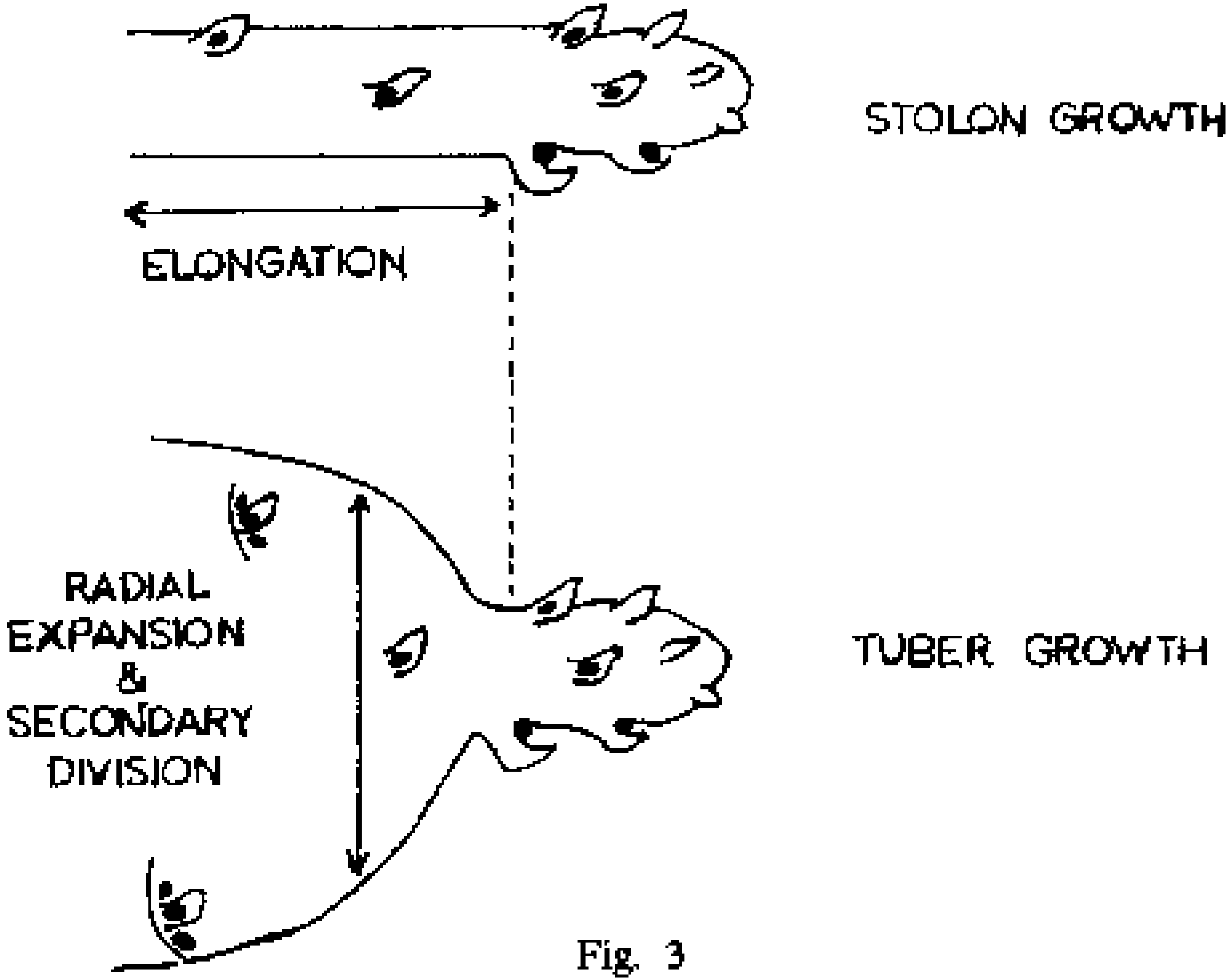

STOLON GROWTH
ELONGATION
RADIAL EXPANSION & SECONDARY DIVISION
TUBER GROWTH

Fig. 3

stances are transported. The conditions which favour initiation are low temperatures, short days, high radiation, low mineral nutrient supply and growth-retarding chemicals such as CCC and B995 (Krugg, 1964; Dyson, 1965; Dyson and Humphries, 1966; Bodlaender and Algra, 1966, Gifford and Moorby, 1967). Reversion from radial or tuber growth to elongation or stolon growth is favoured by high temperatures (Bodlaender, *et al.*, 1964) and periods of water deficit followed by relief from the deficit (Sabalvoro, 1965; McCorquodale, 1966).

b) *Other species*

In sugar beet, the storage root appears to be much more intimately associated with the growth of the leaves and much less subject to change by environmental or experimental treatments than is the potato (Milthorpe and Terry, 1967). The numerous secondary cambia are all initiated at a very early stage and these develop more or less in step with the growth of the leaf surface. Decapitation does not influence cambial initiation although it does stimulate the activity of the cambia once formed. Little is known (at least, by this writer) about the formation of root tubers in species such as the sweet potato and dahlia. In these species only a few of many apparently similar adventitious roots become storage organs; this intriguing response indicates a very localized control and is surely worth detailed study.

INTERRELATIONSHIPS BETWEEN GROWTH OF STORAGE ORGANS AND HAULM

The potato

Those tubers which eventually grow to significant sizes appear to be initiated during the two weeks or so following the appearance of the first tuber. The total weight of tubers during and shortly after this time follows a gradually increasing rate of growth with time; it then enters a long phase of almost constant rate of bulking. Generally, the longer tuber initiation is delayed (i.e. the larger the haulm at the time of initiation), then the shorter is the duration of the phase of increasing rate of growth and the higher and more prolonged is the rate of bulking during the phase of 'constant' rate (Fig. 4). Manipulations, therefore, which result in very early initiation do not usually produce higher eventual yields; much that is gained in earliness is lost in the subsequent lower performance (Burt, 1965; Milthorpe and Moorby, 1967).

Much evidence (cf. Ivins and Milthorpe, 1963) shows that the bulking rate of any one crop in any centre remains constant with time despite appreciable weekly fluctuations of temperature and light. (Severe shortage of water can disrupt this pattern). This behaviour suggests that there is a large measure of internal control during this phase of growth. However, the rates of bulking vary largely between plants subjected to differing conditions prior to initiation (sprout development at planting, cultural conditions, weather, etc), thereby suggesting that the subsequent rate of bulking is largely determined by the state of the plant (reflecting previous history) and the weather conditions near the time of initiation. A clear definition of these conditions, however, is still awaited.

The constancy of the bulking rate in any one crop does not necessarily mean that individual tubers maintain constant rates. Much evidence suggest the contrary; that the rates vary irregularly with time and relative to each other. For example, in one experiment in which $^{14}CO_2$ was supplied to the whole of the foliage, the ^{14}C imported by individual tubers varied by as much as ten times and

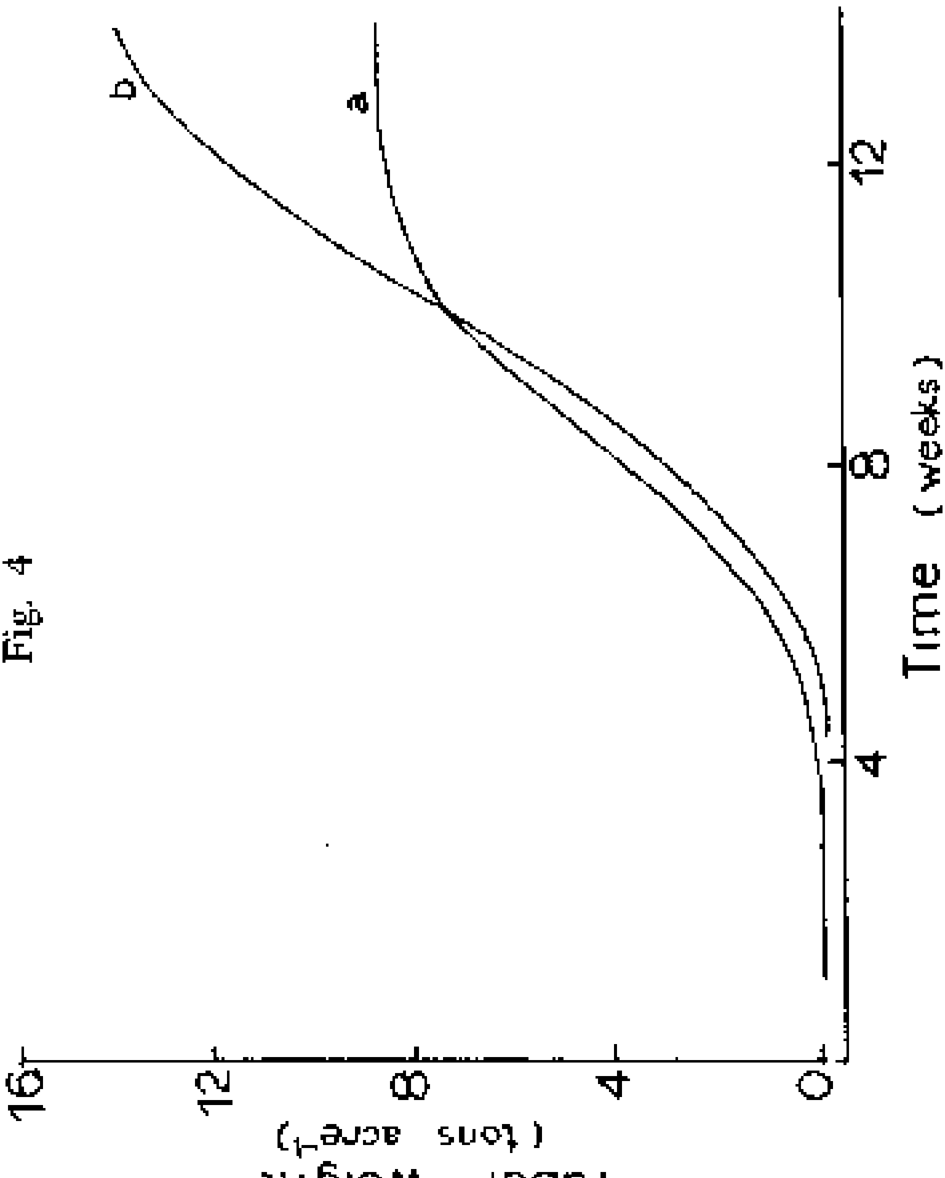


Fig. 4

the largest tubers did not always have the largest content of ^{14}C (Table 1). An interesting feature of this experiment is that it showed that the mother tuber was importing, exporting and metabolizing carbon at this extremely late stage of its existence.

As the tubers increase in size, branch and leaf production gradually cease and the existing leaves senesce leading to the decrease in the total leaf area illustrated in Fig. 1 (Milthorpe, 1963). The rate of decline of leaf area is usually slower the greater the leaf area at the time of initiation. Finally, when little green leaf area remains, the rate of tuber growth declines and ceases. These observations could be claimed to support the general contention that the rate of tuber growth depends on the supply of photosynthate, which is mainly controlled by the extent and duration of the leaf surface (Watson, 1952, 1963). Indeed, Bremner and Taha (1966) and Bremner and Radley (1966) have found a close relationship between tuber yield and the integral of leaf area during the period of bulking assuming all leaf area of 3 cm^2 per cm^2 soil or more to be 3. Other investigators (e.g. Goodwin *et al.*, 1967) have been unable to establish any relationship.

A large amount of evidence, including the relationships with intensity of the sinks (cf. Humphries, this symposium), changing rates of photosynthesis with age, higher net assimilation rates following tuberization, and the constancy of bulking rates in varying environments, suggest that, over wide limits of leaf area, rates of tuber growth are controlled by factors other than the supply of assimilate. As competition effects are pronounced, it is likely that supplies of mineral nutrients to the growing tubers may be involved; it is also conceivable that more subtle growth-substance controls occur. These aspects still await investigation.

All available evidence would suggest that senescence and eventual death of the individual plant results mainly from lack of substrate supply to potential growing points of the haulm. That this senescence is *Erschöpsungstod* (Molisch, 1938), or death by exhaustion, is suggested by the appreciable migration of nitrogen, phosphorus, and potassium from the haulm to the developing tubers; this in turn probably results in decreasing potential rates of photosynthesis which, with the increasing flow of carbohydrates to the tubers, leads to lower and lower supply to the haulm meristems and absorbing roots. New leaves fail to differentiate and the existing leaves decline and die consecutively. There is no evidence of the "flowering senescence" described by Krizek, *et al* (1966) for *Xanthium* and which is obvious in determinate flowering stems of cereals, grasses, raspberry and some other species. This phenomenon is distinguished by profound metabolic changes initiated concurrently with those metabolic reactions which lead to flower induction and is shown by the eventual *browning* of tissues progressing *basipetally*. In the potato, senescence throughout is shown by *yellowing* of leaves progressing acropetally; flowers are often initiated prior to planting; and removal of tubers has long been employed by plant breeders to prevent flower and fruit abscission and in which situation plants continue stem and leaf growth over a much longer time.

The potato in the tropics

In view of the special interests of this symposium, it may be appropriate, albeit dangerous, to speculate briefly on possible manipulations of the physiological responses of the potato in tropical regions. The two environmental components which most influence tuber initiation are temperature and photoperiod, the former being the most important. It would seem essential for adequate tuber initiation that potatoes be grown in a climate in which the temperature is below 20°C for an appreciable proportion (say, 8—10 hours) of each day. High temperatures during the period of tuber growth will also tend to make the terminal buds of the stolons revert to elongation rather than to continued radial expansion but possibly higher temperatures during this phase could be tolerated than around the time of tuber initiation. Although it matters little in respect of physiological responses whether the period of lower temperature is experienced during the light or dark period (Slater, 1964), the most appropriate environment would appear to be one of appreciable incoming radiation but with sufficient night re-radiation to give the required low temperatures.

Provided the temperature requirements are met, the generally shorter photoperiods will tend to accelerate tuber initiation compared with those of more temperate regions. It may often be found that the relative lengths of growing season of different varieties will change compared to those found in temperature regions. Generally, in cool temperate climates, 'early' varieties are less responsive to short days and more responsive to low temperature than are 'late' varieties (Krug, 1963; Caesar and Krug, 1965). As temperature responses are certain to be the more critical in marginal tropical climates, those varieties which are late maturing in temperate regions may be more successful than those which are early, in tropical areas with long periods of low temperatures, the "temperate-early" varieties may tend to be later than in strictly temperate regions.

It will be remembered that there are appreciable differences in the temperature responses of different wild species; *Solanum commersonii*, for example, appears to tuberize well at relatively high temperatures (Davies, 1941). There is therefore ample basal material from which to breed and select new varieties suited to tropical conditions. The appreciable variation in the responses of European varieties (Bodlaender, 1963; Krug, 1963) also allows choice in selecting suitable varieties from existing high-yielding ones.

Another aspect which may be of considerable importance in tropical regions concerns dormancy and storage conditions for seed tubers. There are probably a number of regions where two crops can be produced annually and there will also be a desire to use locally-grown rather than imported seed. Storage, with high ambient temperatures (say, greater than 5 —7°C), may require expensive refrigeration to provide the necessary control; selection of varieties with a long dormant period may then prove advantageous. Frequently in regions where two crops per year are possible (cf. Kawakami, 1962), suitable tubers for spring planting from autumn-grown crops can be obtained but tubers for autumn planting pose greater difficulties. The period between harvesting spring-planted crops and planting the autumn crop is usually too short and that between successive autumn crops too long to obtain suitable seed tubers (say, with 2—4 strong growing sprouts). Here, varieties with a long dormant period may prove advantageous. Cultural practices must of course be adapted to the existing environmental conditions. The general responses with age and to storage environments are enumerated in a number of papers in Ivins and Milthorpe (1963); these provide a background from which the required procedures for particular situations can be evolved.

Sugar beet

As mentioned above, sugar beet is much more closely integrated than the potato and less responsive to environmental variations. Once the "constant" phase of bulking has been established (i.e. by the time the root has achieved a fresh weight of 30—40 g), subsequent wide variations of light and temperature appear to have small effects on the growth of the root (Milthorpe and Terry, 1967). That is, the rate of growth is set by the environment during the first 8—10 weeks of growth and changes little until the environment reaches the lower limits for growth (say, mean temperatures of about 5°C and radiation of about 70 cal cm^{-2} day^{-1}). During the whole period of growth, the ratio of weight of storage root to that of the shoot follows a constant pattern (Fig. 5). This pattern is not influenced by variation in light supply. Low light simply results in slower growth; although photosynthate may then generally be expected to be short, the amount produced appears to be equally shared between all requirements including the storage of sugar in root cells (Fig. 6). Variation in temperature on the other hand influences the pattern as well as the rate of growth — at low temperatures a higher proportion of the (lower) net increase in weight goes to the root and a larger proportion is stored as sugar than at temperatures at which the total growth is more rapid. However, this effect decreases as the plant increases in size: in the later stages of growth large differences in temperatures have little effect. High concentrations of nitrogen in the soil solution appear to work in the same direction as high temperature, i.e. for a larger proportion of the current increment in weight to go into leaf rather than root growth.

There is, over a wide range of environments, a continued and ample supply of substrates from the leaves. Senescence is slow and gradual, the leaf area being maintained in excess of that required for a very long time — certainly, under European conditions, until the temperature has fallen too low for growth.

With sugar beet, as all crops, shortage of water leads to an immediate decrease in the rate of growth of all parts of the plant (Owen and Watson, 1956). However, unless the period of water deficit is unduly prolonged, restoration of the water supply leads to an immediate resumption of growth at a rate higher than that pertaining before experiencing the water deficit. The loss in growth is thereby compensated to an appreciable degree. Sugar beet appears to have, to a greater extent than most other plants, this capacity to make good potential losses induced by water deficits.

Flowering in sugar beet is, of course, induced by prolonged exposure to very low temperatures, old plants being more responsive than young plants. Although there is appreciable varietal variation, young plants may frequently be induced to flower; the resultant "bolting" and diversion of photosynthate to stem and flower growth results in greatly reduced rates of growth of the storage root.

CONCLUSIONS

Young plants of all species are always much more responsive than old plants to variation in the environment and generally root crops are less responsive than leaf and fruit crops, the extremes of stability found in the general category of "root crops". Exploration of the truly tropical species, both in terms of degree of response during ontogeny and in respect of mechanisms involved, is sure to be rewarding — leading to clearer understanding and control in agricultural production and providing more precise understanding of the physiological bases of plant morphogenesis. Generally, very little is known about these species and they provide a rich field for investigation. Even with the

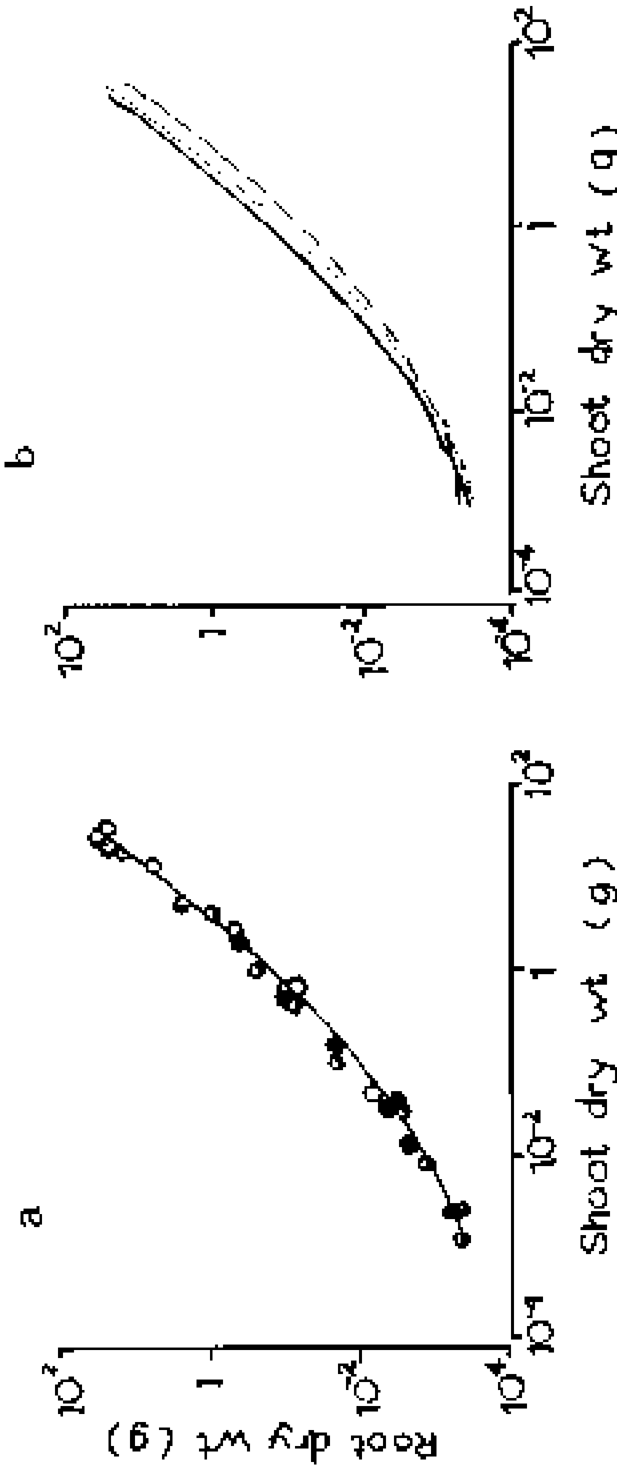
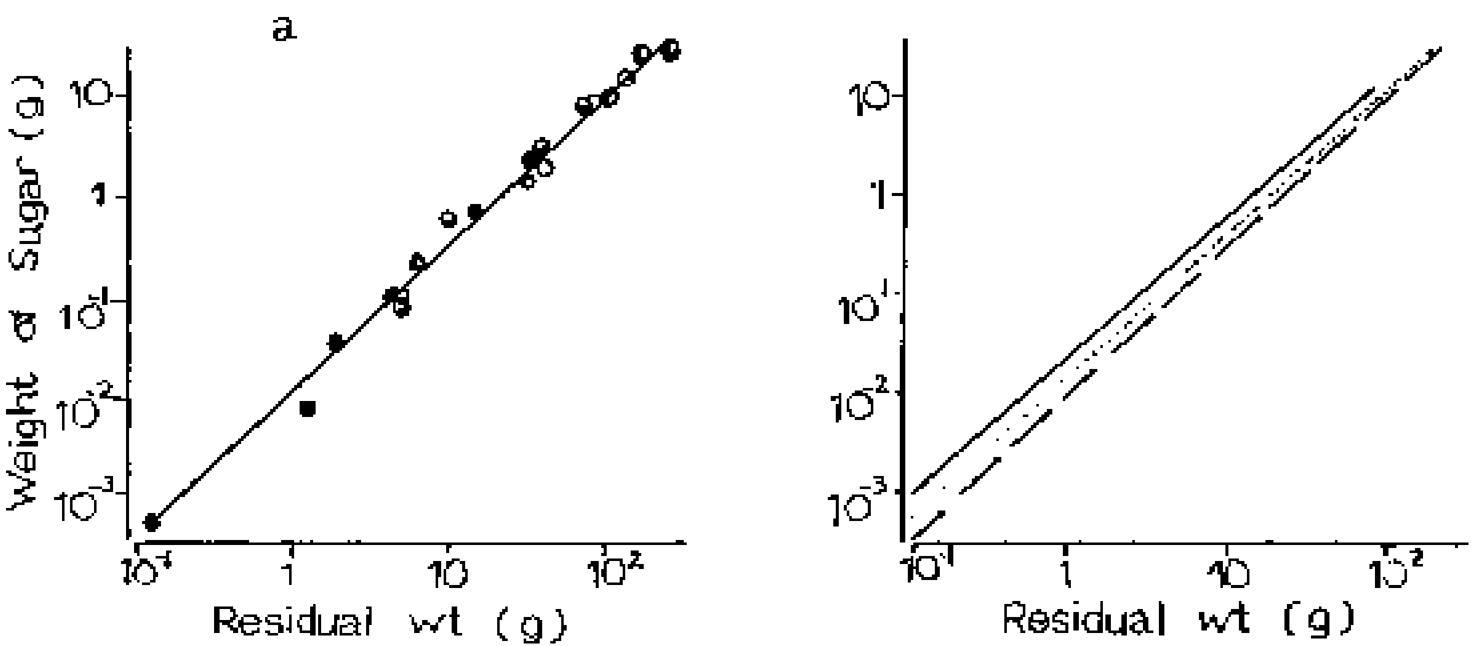


Fig. 5

Fig. 6


a
Weight of Sugar (g)
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-1}
1
10
10^{2}
Residual wt (g)
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-1}
1
10
10^{2}
Residual wt (g)

temperate crops, which have been investigated more extensively, there is but a fragmented and quite inadequate understanding.

One conclusion emerges clearly from agronomic experience during the past few decades. This is that knowledge of the varying responses of a species to its environment throughout all stages of its ontogeny is essential for efficient agricultural production. The era of the costly, inefficient, and strictly limited field experiment in which the final yield only is measured is now ended. It is now recognized that these provide too little information for the effort expended; progress is more rapid where every attempt is made to study the system as thoroughly as possible by analysing sequentially the relevant physiological and morphological responses. This information must be married to the increasing appreciation of the soil and aerial environment; it is only in this way that the agronomist can progress towards a clearer understanding of this complex ecological systems and thereby to contribute to the achievement of higher yields and more efficient agriculture.

Table 1. Content of ^{14}C in mother and daughter tubers of a growing plant

Tuber	Dry weight (g)	^{14}C-content (10^5 counts per minute per tuber) Ethanol-soluble compounds	Ethanol-insoluble compounds
Mother	1.76	1.91	2.21
Daughter 1	5.22	1.16	1.41
2	4.47	7.03	10.02
3	4.06	1.21	1.28
4	3.30	10.62	12.36

Figure 1 Diagram showing the general development of leaf surface and storage organs in potato, sugar beet and sweet potato. The data for potato are generalized to cover the Midland region of England and show the potential net assimilation rate (Ep) (After Milthorpe, 1963). The data for sugar beet are from Scott (1964) and those for sweet potato are from Walter (1966).

Figure 2. (a) Time to emergence and to tuber initiation in relation to length of sprouts at planting and (b) time to emergence as influenced by temperature.

Figure 3. Diagram illustrating differences between stolon growth and tuber growth.

Figure 4. Relation between rate and duration of bulking to time of tuber initiation. Plants such as (a) which tuberize early have a long period of slow bulking and mature quickly; plants such as (b) which tuberize late have a rapid rate of bulking which is maintained for a long time (After Burt, 1965).

Figure 5. Relationships between root dry weight and shoot dry weight of sugar beet when (a) grown under a range of light intensities at 10° and (b) when grown at 10° (continuous line), 17° (dotted line) and 24°C (dashed line). (After Milthorpe and Terry, 1967).

Figure 6. Relationships between sugar content and residual weight of root of sugar beet when (a) grown under a range of light intensities at 24° and (b) at temperatures of 10° (continuous line), 17° (dotted line) and 24°C (dashed line). (After Milthorpe and Terry, 1967).

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EFFECT OF POTASSIUM ON THE DRY MATTER PRODUCTION OF SWEET POTATO

— by —

K. Fujise and Y. Tsuno

The yield of crop is obtained through the process of dry matter production. Therefore, we have carried out the studies on the dry matter production of sweet potato in the last few years, to draw out knowledge which may be utilized for improving cultivation methods. It is considered that dry matter production is composed of three factors. The first factor is photosynthesis, the second factor is respiration and the third factor is distribution of dry matter produced. A series of experiments with sweet potato was undertaken to make clear the influence of the various environmental and internal conditions on these three factors.

However, in relation to actual cultivation technique, it is recognized that potassium is the most effective nutrient for increasing sweet potato yield. Therefore, it is very important to elucidate the relationship between potassium and dry matter production. We intend to report, here, with special reference to potassium of the studies on the dry matter production of sweet potato. Table 1 shows the effect of potassium on the dry matter production of sweet potato. Numerals in the table show the potassium plot as a percentage of the control plot. Potassium used in the high potassium plot is 1.5 times the control plot.

Table 1. Effects of potassium on dry matter production (1962, Sept. 17)

Variety	Norin No. 1	Okinawa No. 100	Kanto No. 48
Total dry weight	109	109	112
Tuber dry weight	119	120	125
Top dry weight	100	96	96
Leaf area index	96	100	91
Net assimilation rate	126	128	123

Note:

1) Numerals show the percentage of high potassium plot for the control plot.
2) Potassium amount fertilized in the high Potassium plot is 1.5 times the control plot.
3) Net assimilation rate was calculated from two determinations, Aug. 27 and Sept. 17.

Tuber dry weight on the high potassium plot was about 20% higher than that of the control plot in the all three varieties, while the top dry weight, that is the aerial parts of the plant showed no difference between both plots. It seems that heavy application of potassium promoted especially the growth of tubers.

The increment of dry weight per unit field area is expressed with the product of "Leaf Area Index" and "Net Assimilation Rate". In this experiment, the "Leaf Area Index" was somewhat low in the high potassium plot as compared with the control plot, but the "Net Assimilation Rate" in the high potassium plot was about 20 to 30% higher than that of the control plot. This may suggest that potassium contribute to the higher photosynthetic activity of the leaves. We have confirmed in many experiments that potassium has really high positive correlation to the photosynthetic rate.

For instance, as shown in the sample correlation of Table II, photosynthetic activity showed a very high correlation with potassium content and a high correlation with nitrogen content, but did not show clear interaction with phosphorus

Table II. Correlation of the three major nutrient elements and starch content in leaves to photosynthetic activity (1963)

	Simple correlation coefficient	Partial correlation coefficient
Potassium	0.824 ***	0.095
Nitrogen	0.698 ***	0.119
Phosphorus	0.559 **	–0.082
Starch	–0.924 ***	–0.648 **

** Significant at 1% level.

*** Significant at 0.1% level.

content. Carbohydrate content in leaves had a high negative correlation with photosynthesis.

As intimate correlation, positive or negative, were found among factors concerning photosynthetic activity, such as potassium percent, nitrogen percent, carbohydrate content, it was not clear which one of these factors showed a true correlation with photosynthetic activity. Then, partial correlation coefficients were calculated between the factors and photosynthetic activity. In the partial correlation coefficient, a high negative correlation was found only between starch content and photosynthetic rate. All the other correlations were insignificant.

We have also observed the photosynthetic depression of the starched leaves in many other experiments. But, it is unknown which exert direct inhibitory influence upon the photosynthetic rate, either accumulation itself of starch in leaves, or translocation velocity of photosynthates from leaves.

Therefore, the diurnal changes of both photosynthetic and carbohydrate rate content in the leaf were determined, in order to evaluate the influence of carbohydrate accumulation in the leaf on the photosynthetic rate. These are shown in Figure 1. Po, that is the photosynthetic rate showed no marked diurnal fluctuation through morning to afternoon, while the carbohydrate content as shown in the figure on the right side showed higher values in the afternoon than in the morning. It is considered from this figure that the carbohydrate accumulation does not exert, at least, direct inhibitory influence upon the photosynthetic rate (see Table III).

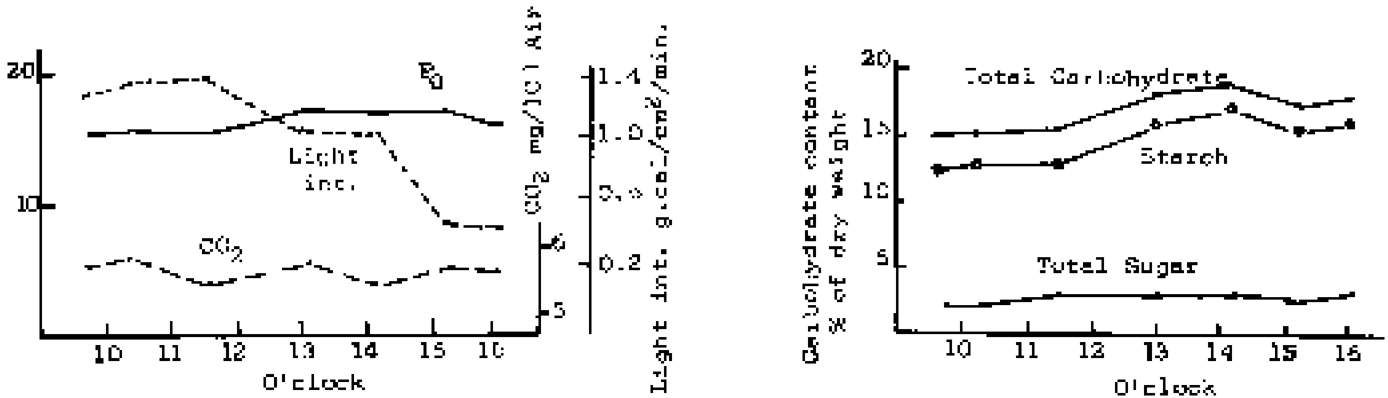
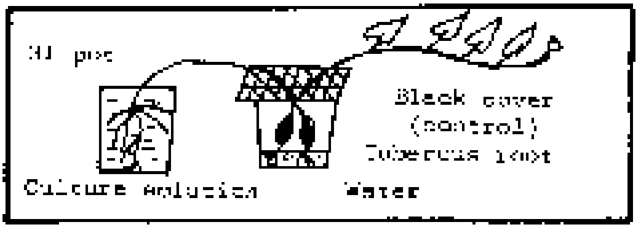


Fig. 1. Diurnal changes of Photosynthetic rate and Carbohydrate content in leaf blade (1968. Sep. 4)

Table III. The influence of exposing tuber to sunlight on photosynthetic activity and its concerning factors.

(Water culture as shown in diagram under the table, 1963)

	%, dry-weight of leaves K_2O	Starch	PoW	Tuber weight g/Plant	Total weight g/Plant
Control	2.50 (100)	16.88 (100)	27.1 (100)	35.70 (100)	96.20 (100)
Exposing	1.88 (75)	20.38 (121)	11.0 (41)	7.10 (20)	80.43 (84)



PoW : Photosynthetic activity per unit leaf dry weight. mg CO_2/g/hr.

The growth of tubers, which are the largest acceptor (sink) of photosynthates, was inhibited by exposing tubers to sun light. The treated plant was increased in starch content of leaves and was depressed in its photosynthetic activity. In the table it was shown as PoW that is the photosynthetic activity per unit leaf dry weight. This is presumably due to the restricted translocation of photosynthates from the leaves. These results suggest that the rate of movement of photosynthates from the leaf (source) to the acceptory tissues (sink) is essential in controlling photosynthetic activity

As shown in the figure under Table III, the absorbing roots and the bulking roots were cultivated separately in the individual pot.

The culture solution was filled in the left pot in which absorbing roots grew. The right pot filled pearlite and watered occasionally. To expose the plot to the sunlight, pearlite was removed at the beginning of tuber bulking. In the control, the surface of the pot was covered by black vinyl film to intercept the sunlight, after pearlite was removed

In figure 2 which was obtained from the results of the gravel culture experiments, sweet potato was grown under identical nutritional conditions for 53 days prior to the treatments, then they were transferred to the different nutritional conditions. That is, C indicates Control, +K indicates high potassium, −N indicates Nitrogen deficiency, +NK indicates high nitrogen and Potassium, +N indicates High Nitrogen, −K indicates Potassium deficiency. Abscissa shows K_2O/N ratio, that is, the ratio of potassium to nitrogen in tuber. Ordinate shows the amount of increased dry weight of tuber during the experimental period.

Increase of the tuber dry weight runs parallel with the K_2O/N ratio in the tuber. The inferior tuber growth in both +N and −K plot was caused by the decreased K_2O/N ratio in the tuber. Therefore, it is very important to maintain high K_2O/N ratio in the tubers.

Figure 3 shows the relation between K_2O/N ratio of tuber and whole plant. As shown in the figure, the K_2O/N ratio of tuber was reflected by that of the whole plant. Therefore, it is necessary to rise the K_2O/N ratio in the fertilizer used, in order to keep a high K_2O/N ratio in the tuber.

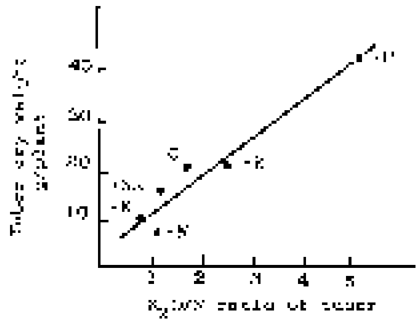


Fig. 2. Relation between K_2O/N ratio of tuber and tuber dry weight (1960).

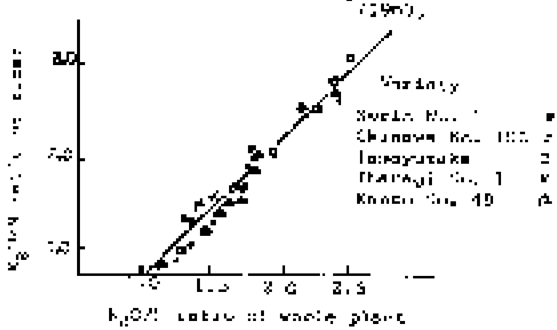


Fig. 3. K_2O/N ratio of tuber compared with K_2O/N ratio of whole plant (1962).

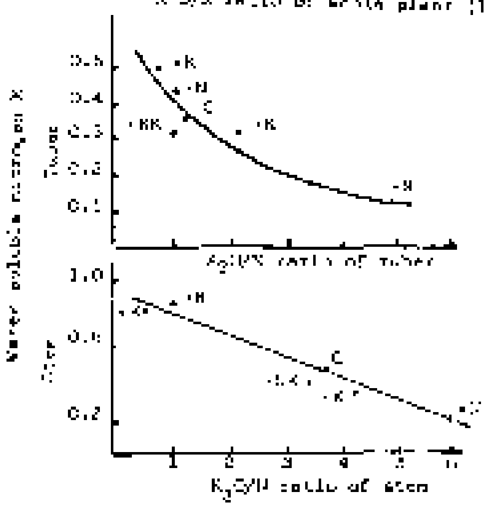


Fig. 4. Relation between K_2O/N ratio and water soluble nitrogen of tuber and stem

Then how does potassium participate in the growth of tuber ? Figure 4 shows the relations between K_2O/N ratio and water soluble nitrogen of tubers and stems. Water soluble nitrogen in the +N and -K plot considerably increased in both tubers and stems. This might be suggesting that protein metabolism was disturbed in the plant of these plots.

Figure 5 shows K_2O/N ratio and water content of tubers grown under the different potassium conditions. The white column shows the control plot, the half-shaded column the higher potassium plot and the shaded column shows the highest potassium plot. A, B, C and D are the varieties. Through all the varieties, the higher the K_2O/N ratio of tubers the more the water content of the tubers. An increase of the K_2O/N ratio in tubers seems to be beneficial for the hydration of tuber tissue.

In Figure 6 the relation between the respiratory rate of tuber and water content of tuber is shown. The water content of tuber was positively correlated with their respiratory rate. Through the increasing of the water content in tuber, potassium acts progressively for the respiratory activity.

In Figure 7, the relation between respiration of tuber and relative growth rate of tuber dry weight is shown. There is a close relationship between growth rate and respiratory rate of the tuber. Tubers showing a higher respiratory rate have also a higher growth rate.

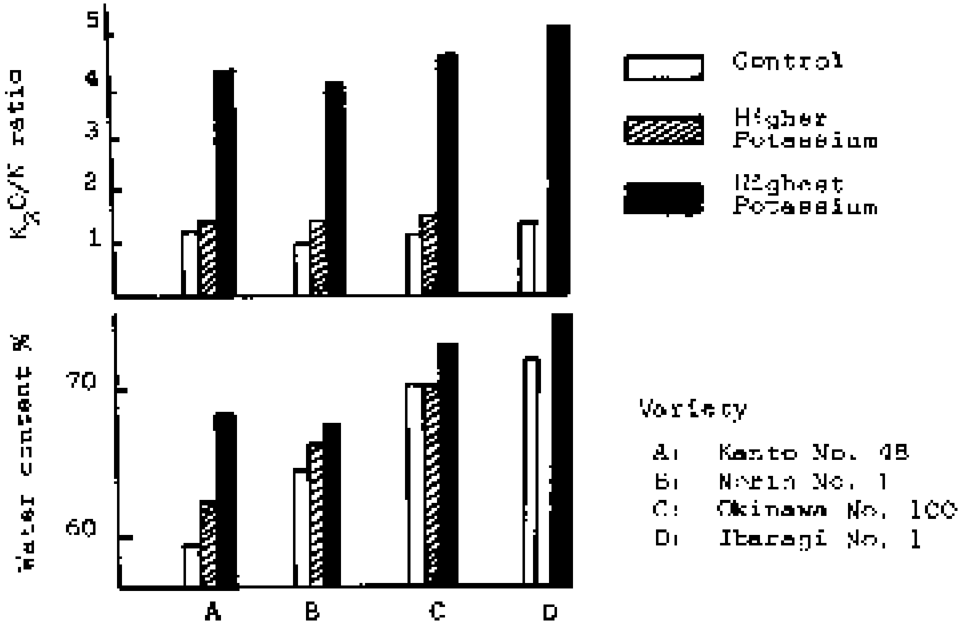


Fig. 5. K_2O/N ratio and water content of tuber grown under the different potassium conditions

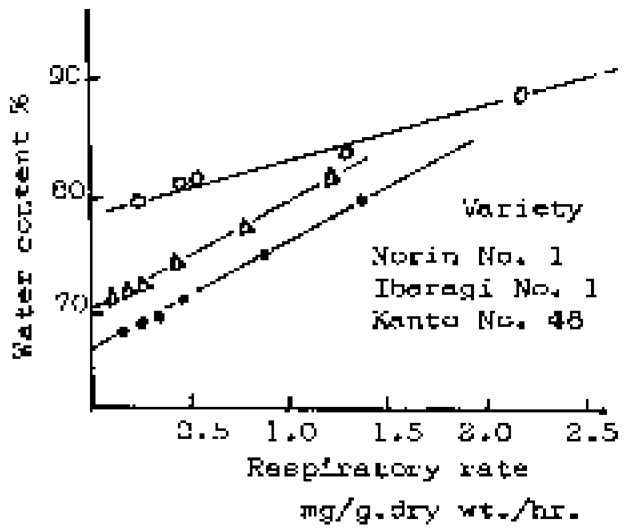


Fig. 6. Relation between the respiratory rate of tuber and water content of tuber (1962)

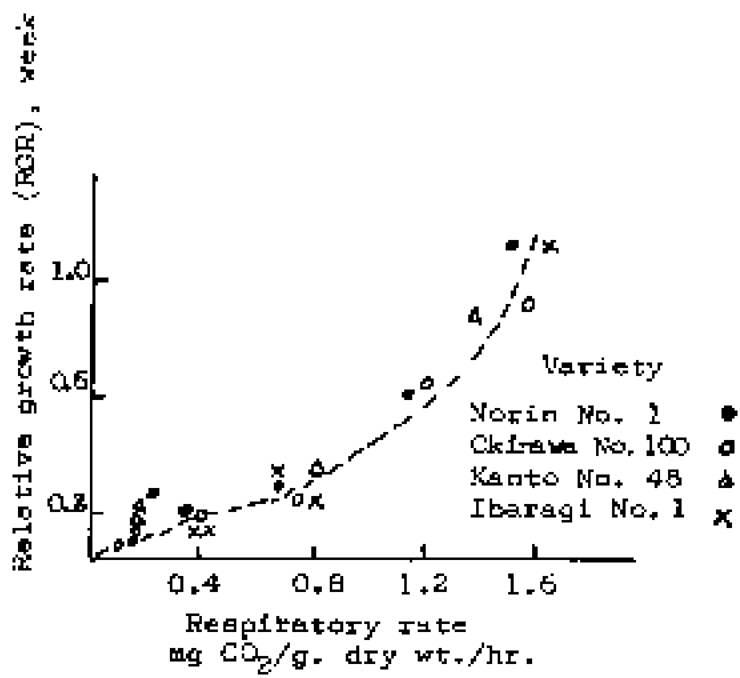


Fig. 7. Relation between respiration of tuber and relative growth rate of tuber dry weight (1962)

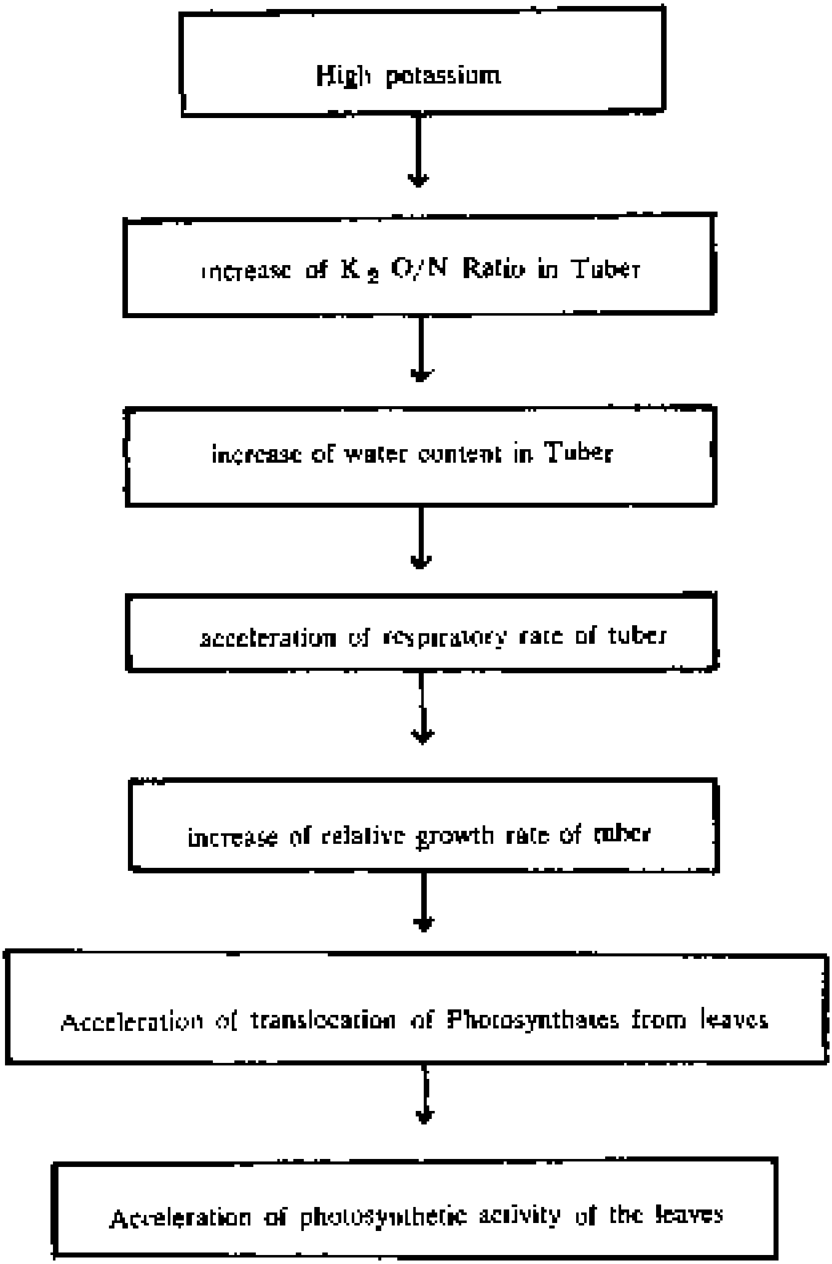


Fig. 8 Effects of high potassium on the acceleration of photosynthetic activity of leaves.

It was the final aim of our studies to increase the tuber yield in the actual cultivation by applying the knowledge obtained from the studies on the dry matter production of sweet potato.

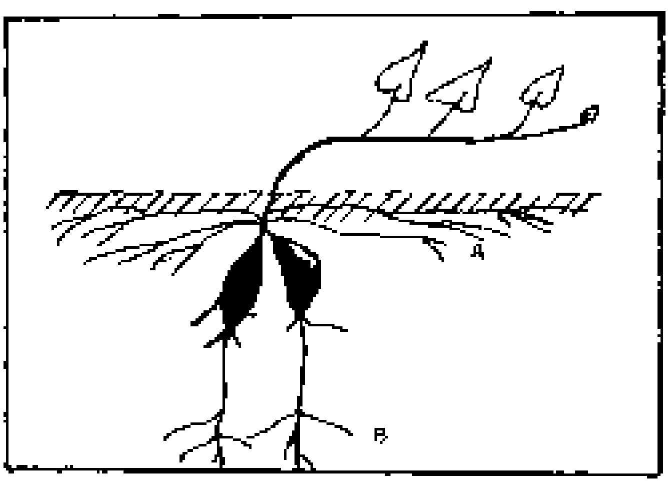
It is desirable to supply continuously a great deal of potassium in order to maintain vigorously the tuber growth until a late growth stage.

Now, as shown in fig. 9, the distribution of sweet potato roots was classified into the two kinds of type, that is, the first, shown as A in the figure was the roots near the soil surface, which were derived from the stem, the second, shown as B was the roots located in the deep layer of the soil, which were derived from the tuber.

The absorption of water and nutrient elements in the roots near the soil surface seemed to decline due to withering of the roots on a late growth stage, although the roots grown deeply in the soil seemed to be healthy until a late growth stage. On the other hand, we observed the facts that potassium existed in the deep layer of the soil on the farmer's field having a splendid harvest.

Therefore, we considered that it would be effective to apply the mineral manure especially potassium deeply in the soil for supplying the mineral nutrients to tuber until a late growth stage.

Table IV shows an effect of the deep application of the mineral fertilizer manure. Part 1 of the table shows the result of the fertile soil. The tuber yield of the plots 4 and 5 manured three major nutrient elements or potassium deeply in the soil were about 35 percent higher than that of the control plot in ordinary plough that is plot 6. The field of this experiment was fertile and the effect of deep plough was also observed.



A: Roots derived from the stem

B: Roots derived from the tuber

Fig. 9. Distribution of two kinds of the root

Table IV. Effects of deep application of mineral manure on the yield of sweet potato.

1) Fertile Soil (1966)

Plot	Top wt. kg/10a	Tuber weight kg/10a	Index		Dry Matter %	Surface N	Surface P	Surface K	Deep Place N	Deep Place P	Deep Place K	
I	3323	2696	100	121	32.4	3	10	10	—	—	—	Deep Plow
II	3960	2706	100	122	30.6	6	20	20	—	—	—	(27 cm)
III	3062	2850	106	128	33.2	3	10	30	-	—	—	
IV	3535	3029	112	136	32.2	3	10	10	2	8	8	
V	3233	2972	110	134	33.2	3	10	10	—	—	20	
VI	—	2223	—	100	—	3	10	10	—	—	--	Normal Plow

Amount of mineral manure elements kg/10a

Variety Tamayutaka, Planting : May 25th, Digging : Oct. 24th

2) Poor Soil (1965)

Plot	Top wt. kg/10a	Tuber weight kg/10a	Index	Dry Matter %	Surface N	Surface P	Surface K	Deep Place N	Deep Place P	Deep Place K	
I	—	1890	100	33.3	4	5	20	—	—	—	Normal Plow
II	2930	2450	130	32.9	4	5	20	—	—	—	
III	3140	2360	125	33.8	4	25	20	—	25	—	Deep Plow
IV	3290	2450	130	33.0	4	5	10	—	—	10	
V	3160	2640	140	33.3	4	25	10	—	25	10	(40 cm)
VI	3140	2840	150	32.0	2	25	10	2	25	10	

Amount of mineral manure elements kg/10a

Variety : Tamayutaka, Planting : May 25th, Digging : Oct 20th

In the poor soil, as shown in Part 2 of the table, the effect of deep application of potassium only, that is, (Plot 4) was not more than that of the deep plough, that is (Plot 2). In this case, the deep application of three major nutrient elements, that is, (Plot 6), was only effective.

In the other experiment, it was observed that the deep application of potassium only in the poor soil withered the roots, whereas, the deep application of the nutrient elements kept the roots holding healthy.

It would be important that the balanced absorption of three major nutrient elements is kept on until a late growth stage for increasing the tuber yield. Thereby, the deep application of mineral manure would be an effective method.

Dr. Sidrak :

Prof. Milthorpe, if I have understood you correctly, at a particular stage of growth of the stem and leaves in Irish potato, a slowing down of the growth of the shoot and leaves takes place. Does this cause initiation of tuberisation or increase in the rate of tuberisation of the Irish potato? If so, can this be done on a large scale? Can we decrease or arrest the growth of the shoots in order to increase the tuberisation?

Prof. Milthorpe :

If leaf and stem growth slows down, then tuber initiation and growth usually commences. This can be achieved by applying stem-elongation retardants — substances like CCC and B9. Also, in natural conditions when the tuber starts to grow, then lateral branching and the initiation of leaves from the existing stems also cease.

I think that in the Irish potato this is pretty much a straight competition effect, involving mobilisation of mineral elements. This appears to be the basis of senescence in this plant. In some other plants there are quite different responses, including very profound metabolic changes, involved in senescence. But I do not think that this is the situation in the Irish potato.

Dr. Sidrak :

Dr. Fujise, you mentioned that the increase in the potassium content of the leaf will cause an increase in the photosynthetic activity of these leaves. Does this continue to be the case, regardless of the age of the leaf?

Dr. Fujise :

The close relation between photosynthesis and potassium concentration is observed among the same aged leaves, but it is not observed among the leaves of different age.

Although potassium concentration in the younger leaves near the top of stem is not high, they have the higher photosynthetic activity.

When nitrogen content in leaves is low, for example, below about 2% in our experiment, photosynthetic activity is lowered, regardless of potassium content.

As Dr. Humphries indicated, we have also considered that photosynthetic activity will be controlled by the rate of movement of photosynthetic product from the leaves (source) to the tuber (sink).

Potassium will cause the acceleration of photosynthetic activity of the leaves, through the increment of tuber growth.

Then, it is more essential that potassium is continuously supplied to the tuber, until a later growth stage.

Mr. Coursey :

I would just like to make a very brief comment on Prof. Milthorpe's paper, to note that the growth patterns of the Dioscorea yams are in general, very similar to that of the Irish potato. I think the lag in tuber development after the leaf growth is rather long. Perhaps, it is somewhat intermediate between Irish potato and sweet potato.

Prof. Milthorpe :

May I ask a question following that? Is it possible to change readily the time of tuberisation relative to leaf growth in Dioscorea?

Mr. Coursey :

There is a great degree of plasticity in time of development of tuber. Even in one species there is adaptation to very wide ranges of climate as far as growth period is concerned. As far as type of tuber is concerned, that is an extremely complex issue.

Mr. Williams :

Can any of the speakers in this session suggest a rapid but reliable index which could assist the plant breeder in selecting out phenotypes which may, with a high degree of reliability, possess physiological characteristics, highly correlated with plant habit and tuber yield?

Prof. Milthorpe :

There is, of course, a working party in this Symposium examining this subject and I am sure that they will provide a much more profound answer than I can at this stage. Generally, I doubt if there is any one simple and reliable index which can be used to assess yield potential, except the yield itself. It is very important to follow the growth of the plant throughout its life in order to understand its behaviour and to assess both its good and poor qualities.

Dr. De Gras :

On the point of the pattern of tuber growth relative to the growth of the leaf stem I have noticed in two varieties of Dioscorea that the growth of the top is ceasing when the tubers begin to grow. This response will not be discussed in my paper, but I have a very precise indication about that.

Prof. Milthorpe :

I do not know whether I can profitably comment on what you have said. It seems to be a very similar situation to that in the Irish potato.

Mr. Gooding :

I observe that under Barbados conditions tuber bulking commenced within 6 weeks after planting and tubers were harvested 16-18 weeks after planting. This was considerably earlier than Walter's data from Trinidad presented as Fig. 1 by Prof. Milthorpe. Prof. Milthorpe, could you suggest some way by which Irish potatoes in the tropics may be manipulated to obtain higher yields? The one thing we cannot alter is uniformly high temperature. But I suspect that with all the physiological knowledge that is available today, there may be several "tricks" that could help us. The second question is to Dr. Fujise. In his table 1 he indicates that applying potassium at 1.5 times the control rate gave an increase in yield of approximately 30% in the tubers. What was the level of fertilisation in this experiment?

Dr. Fujise :

Effect of potassium on the tuber yield is different according to the nitrogen level and potassium level of the soil. Although, it is difficult to apply general cases, it, however, is important to keep the adequate ration of potassium to nitrogen 2-3:1.

If we manure 2 or 3 times potassium to nitrogen, it would be possible to increase 50% or more of tuber yield, compared with the case in which potassium is not manured, except in the special poor soil or in the nitrogen too rich soil.

Dr. Royes :

You mentioned, on the plasticity that existed in both the time of tuber initiation and the rate of tuber bulking, which varied considerably with various environmental factors. Have you found similar variations between varieties? And the relative extent of each in the environmental plasticity to the variation of the varieties.

Prof. Milthorpe :

Yes, there is quite a large varietal variation, but I think that one can almost achieve as much by agronomic management, of the one variety as one can, by altering genes, involving different varieties. Certainly, the late varieties of Irish potatoes, that is ones that initiate tubers late and give the highest yields, are more responsive to short days and to low temperatures than the early varieties. This means that when they are grown — as they are in Europe — under unfavourable daylengths, we have a short-day variety which is initiating in the longest days of the year, because they are more responsive means that they delay tuber initiation. I think the key to some of the problems in tropical conditions may well be getting the seed bud tubers in the "correct" stage, at the time of planting. This again, one can do by 'management during storage', but this might be very expensive because it requires strict control of the temperature. Nevertheless, it is likely that the major problem may require very careful manipulation of the seed tubers between the time of planting and the time of production.

Dr. Wilson :

We have been coming around to the idea that the whole process of tuber bulking is the end result of a series of morphogenetic changes. I wonder whether Prof. Milthorpe could comment on this statement in relation to his observations with Irish potatoes?

Prof. Milthorpe :

I do not know whether I can add very much more to what I stated in my paper which I think emphasized this viewpoint.

Dr. Wilson :

I was thinking along the lines that tuber bulking is more dependent on these morphogenetic changes rather than the total amount of photosyntate produced.

Prof. Milthorpe :

I think that this is so. As I was trying to say before, I believe very firmly that the rate of bulking of the plant, and thereby the final yield, is set by about the time of tuber initiation. Thereafter, apart from one effect - the effect of shortage of water — the control is almost entirely by internal factors, the whole bulk of complex factors inside the plant.

Mr. Williams :

Mr. Gooding reported in a seminar recently presented at this university that tuberisation in the alata yams after establishment seemed to be delayed for a period of about 3-4 months after which tuber bulking and the elaboration of leaf area was very rapid. He apparently correlated this with the time taken for the morphogenetic differentiation of what apparently was a tuber primordium. We have made some similar observations in yams held in storage. Can you tell me if the pattern of development as suggested by this data diverges to any great degree from other root crops known to you?

Prof. Milthorpe :

No, not really. I think that, in a sense, the Irish potato will always respond in this way, but not to such a marked degree as you pointed out. I do not know if you established for this plant the case of tuber development. But certainly, it is true that in the Irish potato, if tubers are initiated at very early stages they do not grow rapidly at first; they grow at very slow rates for as long as 3-4 weeks before the rapid phase of growth commences. It might very well be so with the species of yams that you mentioned. But in the sugar-beet this would not be true no matter how the plant is manipulated. This plant is under what we may call "genetic control" as distinct from "environmental control".

Dr. Radley :

I should like to ask Prof. Milthorpe whether he had made any control environment experiments to establish his statement that events at or the time of tuber initiation control the subsequent bulking? This is a very important point, which I think may be readily explored by growing potatoes under different conditions and then switching plants from one environment to another and determining whether or not rate of bulking does significantly change.

Prof. Milthorpe :

No. I agree that this is a most important experiment to do and it is one which we have not done. The evidence on which I based this statement is perhaps tenuous, being solely the constancy of the rate of bulking with time in a varying environment

Dr. Royes :

Referring again to Mr Gooding's data of the early start of tuberisation and the fact that you mentioned that plants do not 'play the game' if you made them start tuberisation early, they tend to end up with a lower quota of tubers — in fact we want to change it very gradually to a much later date of tuberisation and therefore get a larger bulk of tubers at the end.

Prof. Milthorpe :

This is quite possible again. But I think that I cannot comment in detail here, because I do not know much about the plant. But I think that this is quite a possibility. The only way, of course, is to follow growth of the plant throughout its cycle, and see what is happening and attempt to change the response.

The type of response will change quite a bit with the species and this is why I tried to emphasise the differences between Irish potatoes and sugar-beet because they provide two extremes of plasticity.

Dr. Wilson :

I would like to make a comment on Dr. Radley's question, because it is the thesis on which some of my ideas on the importance of morphogenetic changes in tuber bulking are based. Now, some experiments, similar to those which you described, have been done by Evans' group at Cambridge and they found that when plants are changed from one set of conditions to another, e.g. from low temperature to high temperature, there were considerable alterations in morphogenesis of the plant. Such plants took some time to establish themselves in the new environment but the morphogenetic changes involved seemed to control photosynthate production and utilization rather than vice versa

Prof. Milthorpe :

This is a comment on your comment. I believe that one needs to be cautious in arguing from the purely vegetative plant to the root crop. Also I think that the responses which you mentioned are those which are found in the very early stages of growth. The more the plant advances through its growth cycle, the less it responds to any changes in environmental factors.

Dr. Wilson :

I thought that it was rather interesting that in experiments carried out by Whitehead and Meyersough, along similar lines, fruit yield was found to be related to what was described as 'a photosynthetic entity' which was itself an expression of morphogenetic changes that occurred throughout ontogeny.

THE DEPENDENCE OF PHOTOSYNTHESIS ON CARBOHYDRATE SINKS: CURRENT CONCEPTS.

E. C. Humphries

Rothamsted Experimental Station, Harpenden, Herts.

The process of photosynthesis that leads to reserves accumulating in plants depends primarily on external conditions, especially radiation and temperature, but there is much evidence that internal factors may limit productivity. Thus, fixation of CO_2 may become restricted when products of photosynthesis accumulate in leaves because plants lack suitable sinks into which carbohydrate can be diverted and translocation is slowed down. The object of this paper is to consider both our present state of knowledge of this subject and also some of the conditions affecting sink size.

It is by no means a new idea that products of assimilation may limit photosynthesis — it was demonstrated in the latter half of the last century when plant physiology was emerging as a separate subject. Even before Ewart's experiments in 1895 (Ewart 1895) several relevant observations were recorded in the literature. Ewart observed that when mature leaves of *Vitis* were enclosed in an atmosphere of 10% CO_2 , assimilation ceased after 4 days but was restored after a period of darkness when carbohydrates were used up. Thung (1928) and Barton-Wright and McBean (1932) found potato leaves infected with leaf roll virus photosynthesised less than healthy leaves, presumably because products of photosynthesis accumulated in infected leaves. Kursanov (1933) found that detached leaves of Medlar kept in the dark for 4 days and then illuminated assimilated more than leaves illuminated daily. Leaves with their petioles in glucose solution assimilated less than leaves with their petioles in water. Ringed *Pinus* plants assimilated less than unringed plants. He concluded that accumulation of carbohydrate was probably the chief but not necessarily the sole reason for assimilation being decreased. During the last 20 years many lines of work have suggested a causal relation between accumulation of assimilates and lessening of assimilation, and Muller (1960) reviewed some aspects.

Evidence from detached leaves

Goodall (1945) found that detached tomato leaves assimilated slower than attached leaves and the difference was greater in the afternoon than in the morning. Similarly, Barau (1960) found that photosynthesis slowed in detached leaves of tea and sunflower as the products accumulated, as also did Hall and others (1966) with blueberry leaf disks. Other instances are given by Livingston and Franck (1940).

Evidence from removal of plants parts

More assimilate is likely to accumulate in detached leaves than in leaves attached to plants but there is much evidence that they can also accumulate in the leaves of intact plants that lack adequate sinks for carbohydrate, such as rapid vegetative growth, fruits or storage organs. Nosov (1959) observed that removing cotton bolls halved photosynthetic activity of the leaves in 24 hours. Kiesselbach (1948) similarly found removing maize flowers decreased fodder yield by 27%.

Moss (1962) also examined the effect of barrenness in maize on net assimilation of CO_2; bagging immature flowers slowed CO_2 assimilation and increased sugar content of the tissue. From flowering to harvest dry matter increased only about half as rapidly in barren plants as in plants with normal ears. Moss also found that removing tomato fruits diminished daily assimilation to only 12% of the initial rate. Khairalla and Whittington (1962) observed that net assimilation rate increased in tomato plants towards the end of their growth period, an effect that might be associated with demands of rapidly developing fruits. Zakhar'yants and Ionesova (1964) infiltrated leaves of cotton and maize with sugar solutions — in both species photosynthesis decreased about 80% soon after treatment but partially recovered later. Vernalisation of *Lolium* seemed not to influence growth in the vegetative stage but speeded growth in the reproductive phase, probably because reproductive tillers grow faster than vegetative tillers because intercalary meristematic tissue functions as a sink for assimilates (Silsbury, (1965). Hartt -K (1962, 1963) concluded that accumulation of sucrose during photosynthesis of sugar-cane leaves inhibited photosynthesis and that a fast rate of photosynthesis required efficient translocation. ^{14}C photosynthate moves through detached sugar-cane blades as fast as in entire plants at first but slowed with time when sucrose accumulated at the base. Translocation was increased by supplying a sink as a leaf attached to a 4-joint cutting of stem or by darkening the base of the blade below the fed part. Hartt (1965) showed that when roots are cold ^{32}P moved upward in the xylem and the downward movement both of organic compounds of ^{32}P and photosynthate was slowed down. Rock and Bolas (1956) found that the vigorous apple stock Crab C has a greater mean net assimilation rate than Malling IX irrespective of nitrogen supply. Maggs (1958) suggested the increase in net assimilation rate as apple root stock grew larger was because the sites for deposition of synthesised material were relatively larger. Two root stock varieties, Malling XVI and Malling II, showed a different dry weight increase in spite of similarity of leaf development. The dry weight increment distributed in the large root system of Malling XVI resulted in a relatively greater cambial surface than when deposited as thickening in the stem (Malling II). Maggs thought that the more extensive cambial surface provides a larger sink, which makes the foliage above it more efficient. He (Maggs 1963) found that 2-year-old apple trees with flowers or fruits removed produced less total dry matter per unit area of leaf than trees with flowers and fruits. Chandler and Heinicke (1925, 1934) also had evidence that presence of a fruit crop increases leaf productivity.

If leaves sometimes function below their full photosynthetic efficiency, removal of a part of them should make the remainder more efficient. Kiesselbach (1948) found removing half of each leaf of maize at time of silking curtailed further increment of dry matter by only 22% of normal. The efficiency of dry matter elaboration by the remaining half leaves was increased by 56% per unit of leaf area. Allison and Watson (1966) also found that, when laminae were removed from maize, less dry matter remained in the stem and the photosynthetic efficiency of the remaining leaves was apparently increased. They suggest that differences in grain yield of maize, for example between varieties, may therefore depend on differences in the capacity of the grain to store dry matter as well as on the size and efficiency of the photosynthetic system. In other words, sink capacity of grains may be an important factor in deciding yield. Maggs (1965) also showed that removing some apple leaves increased the rate dry matter was produced by the remaining leaves. Similarly, Humphries and Dyson (1965) found that removing some potato leaflets or axillary shoots increased the efficiency of remaining leaves. May (1960) suggested that slow translocation in some grasses limited photosynthesis because assimilates accumulated. Preventing photosynthesis for a while at mid-day increased yields by up to 50%, by allowing excess carbohydrate to be removed (Went, 1958). Stern (1965) points out that radiation does not appear to be the primary limiting factor determining cotton yield and emphasises the importance of suitable carbohydrate sinks.

Evidence from manipulation of sink size

Experiments in which size of sink is changed also support the idea that sink capacity and photosynthesis are positively correlated. Burt (1964) found that removing potato tubers 21 days after they formed slowed the net assimilation rate and he suggested assimilation by the leaves in bright light may be restricted by their ability to use or store products of photosynthesis. Burt (1966) further showed that, when tubers developed slowly in the cold, net assimilation rate was less than when tubers developed faster. He concluded that environmental factors may regulate sink strength and plant growth by controlling either the initiation or development of carbohydrate sinks (or both); conditions that favour sink initiation (few nutrients and cold tubers) may differ from those that favour use of carbohydrate by sinks (abundant nutrients and warmth). Nosberger and Humphries (1965) confirmed that removing tubers depressed net assimilation rate of potato plants and increased the carbohydrate content of stems and leaves. Assimilation was depressed still more when lack of nitrogen limited growth. Plants with abundant nitrogen developed secondary sinks, such as second order lateral branches and aerial tubers, so removing the primary sinks—the tubers—had less effect on net assimilation than in plants deficient in N.

Mush (1961) showed that the attachment of the mother tuber depressed photosynthesis; which he attributed to it supplying carbohydrate to the leaves. Bremner and El Saeed (1963) suggested that the smaller food reserves in small potato seed tubers are to some extent compensated by these reserves affecting photosynthesis less than that in larger seed tubers, and may explain the greater efficiency of small seed. Burt (1965) found that spraying potato plants with urea increased the net assimilation rate, which may reflect the greater 'sink' strength of the tubers rather than the direct effect of nitrogen on photosynthesis and translocation. Tsuno and Fujise (1965), who inhibited tuber growth in sweet potato by exposing the tubers to light, found the treated plants photosynthesised less and had more starch in their leaves but they detected no change in the diurnal course of photosynthesis and concluded that the rate of movement from the leaf, and not accumulation of carbohydrates, controls rate of photosynthesis. Wilson (1966) points out that arctic plants have small net assimilation rates probably because sugars accumulate in amounts that depress assimilation. Cold slows respiration and new plant growth more than it slows rates at which assimilates are produced. Thus, the Q_{10} for respiration is of the order of 3 but for net assimilation is about 1.2. Arctic plants also tend to accumulate sugars because they are usually deficient in N.

Substituting a more efficient sink for a less efficient one can also increase net assimilation. Thus, when Thorne and Evans (1964) grafted tops of spinach beet plants, which have poorly developed tap roots, on to roots of sugar beet, the spinach beet leaves assimilated more presumably because the sink was greater. Sweet and Wareing (1966) also found manipulating the sink in *Pinus radiata* seedlings by removing the plant apex below expanding leaves influenced net assimilation; after 8 or 16 days net photosynthesis had decreased, more in bright than in dim light. However, this could have happened because the sink for assimilates was smaller or because the decapitated plants contained less auxin. The possibility that auxin may affect rate of photosynthesis will be discussed later.

Restricting root growth in cotton (Taylor and et al 1963) and in sugar beet (Wheeler, 1966 pers. comm.) affected growth and yield, but whether because leaf efficiency was impaired by diminishing sink size, or for other causes, is not certain. Humphries (1963a) varied the rate of root growth of detached rooted leaves of *Phaseolus* either by use of growth substances or by varying the temperature around the roots. These rooted leaves do not produce buds and the roots are the main sink for carbohydrates produced in the lamina. Net assimilation was contolled by the rate carbohydrate moved from source to sink, which in turn depended on the growth of the root system. Experiments with rooted leaves of two species of *Phaseolus* (Humphries, 1967) showed that one species rooted more freely than the other in the cold and then assimilated faster than the species that rooted less well. At warmer temperatures, the root growth and net assimilation rates were similar in both species. CCC lessened assimilation in *Sinapis alba* (Humphries, 1963b) either because it directly inhibited photosynthesis or because the dwarfed stem of treated plants provided only a small sink for photosynthates. By contrast in sugar beet CCC did not affect net assimilation possibly because the roots provide a large sink (Humphries and French, 1965). In potato, CCC increased leaf efficiency (Dyson and Humphries, 1966) possibly because treated plants tubered earlier. In total the evidence suggests that CCC does not act directly on assimilation but indirectly by altering sink size.

When all the assimilate which would normally accumulate in a sink can be accommodated in stems, e.g. Nosberger and Thorne, (1965); Allison and Watson (1966), assimilation rate is not altered.

Brougham (1961) suggested that plants with large storage organs have an evolutionary advantage. In the same way, production of bulbils which occurs in isolated genera of several plant families, may be an important means of isolating surplus carbohydrate (Burkhill, 1960).

Effect of environment on sink development

Mineral nutrition greatly affects sink size. Thus, Watson and Russell (1943a, 1943b) and Woodman and Paver (1944) showed that nitrogen increased the ratio of roots to tops in mangolds and turnips, which Aaney (1952) suggests is because the meristem activity of the leaf primordia is less affected by nitrogen than the cambial activity of the roots. Potassium increases tuber yield of sweet potatoes without any corresponding effect on the growth of tops, and Tsuno and Fujise (1965) suggest potassium acts by accelerating translocation of carbohydrate from leaves. Austin (1962) found lack of nitrogen increased amount of sugar in red beet leaves possibly because it limited assimilation by slowing translocation of sugars from the leaves.

Other environmental factors are important in determining growth of sinks especially in plants like *Solanum demissum*, *Dahlia* and *Helianthus tuberosus* where exposure to short days is necessary for storage organs to form. It would be instructive to compare the net assimilation rates of such plants under long and short days. Differences in assimilation rate in different photoperiods were noted by Bode (1942): short-days increased it in *Kalenchoe*, which may indicate a diurnal decline in which assimilatory efficiency is large at the beginning of the light period but less when assimilates accumulate. Diurnal variations in dry weight accumulation have been noted by other authors (e.g. Goodall, 1945). Went and Engelsberg (1946) suggested that photosynthesis stops when sucrose reaches a concentration of 20% of the fresh weight.

During periods of stress, e.g. drought, plants grow slowly but when the stress is removed, they often grow and assimilate faster than unstressed plants. The increase in net assimilation when plants are watered after drought, as Owen and Watson (1956) and Orchard (1963) found with sugar beet, could result from increased demand for assimilates by meristems previously retarded by water stress. If this explanation is right it would be necessary to demonstrate accumulation of carbohydrate in the leaves during drought, and Kemper et al (1961) specifically attribute the increased growth rate after relieving soil-moisture stress to accumulation of carbohydrate during the drought.

Evidence for sink effects in normal plants

The evidence for a relationship between sink size, which is often equated to growth of a plant organ and assimilation rate is readily demonstrated when the plant is in some way manipulated or parts amputated, but it is more difficult to show that sink phenomena act as important internal factors controlling photosynthesis in intact plants. Most plants possess a ready means of using excess carbohydrate, namely, by increasing growth of the root system. There is now abundant evidence that the growth of the root system does not necessarily exactly parallel, day to day, the growth of the shoot. It has already been pointed out that the roots of detached leaves provide an adequate sink for carbohydrate produced by the leaves provided conditions favour root growth. The root system of an intact plant can probably accept all carbohydrate the shoot can supply. The root system is an efficient carbohydrate sink because it is potentially of unlimited growth and has many meristems, whereas shoot meristems are limited in number and their production possibly under internal control (Fulford, 1965; Humphries, 1966). Thus, the morphological nature of the root makes it an efficient carbohydrate sink and it can function as a safety valve for surplus carbohydrate from the shoot.

There is considerable evidence that root growth is directly affected by assimilatory conditions. For example, Muenscher (1922), Shirley (1929) and Reid (1929a) all showed that bright light increases root growth proportionally more than shoot growth in cereals and herbaceous plants. Also, the proportion of shoots to roots differs in different seasons, and long days preferentially encourage roots. Wassink (1957) showed there was a close relation between light intensity and root growth which is decreased by shading (Blackman and Templeman, 1940). Removing buds from cotton increased the root system as a percentage of the whole plant from 15 to 30 (Eaton, 1931) and a greater percentage of labelled photosynthate entered the root system of soybean (Nelson and Gorham, 1959) and sweet potato (Sekioka, 1962) in bright light than in dim light. Starck (1963, 1964) concluded that roots affect translocation from shoots because they are important sinks of assimilates. Translocation of ^{14}C assimilates in pine seedlings with well-developed roots exceeded many times that in plants with a poorly developed root system (Nelson, 1962). Davis and Lingle (1961) suggested that cold diminishes the effectiveness of tomato roots as a sink for phloem-transported material. When photosynthesis is increased by increasing atmospheric-CO_2 concentration, root growth increases relatively more than shoots (Reid, 1929b), and White (1937, 1938) concluded that increased net assimilation rate from any cause produced *Lemna* colonies with longer roots.

It seems a general principle for roots to respond more readily than shoots to a supply of carbohydrate. Perhaps variation in root growth rate is usually adequate to deal with fluctuations in carbohydrate supply from the leaves caused by the changing environment without carbohydrate accumulating in the shoot and affecting the rate of photosynthesis. But there is evidence that the root system is not always an adequate sink for surplus carbohydrate; for instance, the fibrous root system of plants with underground storage stems or roots seems unable to grow enough to use all the carbohydrate the shoot can produce. Thus, removing tubers from potato plants, as already mentioned, depresses assimilation (Burt ; Nosberger and Humphries, loc. cit.). Also, preventing grain developing on corn plants increased root weight by only 7% (Kiesselbach, 1948) which did not make them an adequate substitute for the ear as a storage organ. The amount of carbohydrate diverted to the root system will perhaps depend on the distance it has to travel. Thrower (1962) showed that in general the amount of assimilate exported from an expanded leaf to the apex and root is inversely proportional to the distance from those sinks. Fibrous root growth slows or stops when flowering and fruiting begins and the root loses its function as a carbohydrate sink. This may be because of competition for carbohydrates or because, as Resende (1947) and Selim (1956) suggest, auxin is used in the growth of the inflorescence.

When usual storage of carbohydrate is denied to the plant, by removing storage organs or meristems, carbohydrate accumulates in cells of the stems, leaves and fibrous roots, and this seems to be a pre-requisite for the depression of photosynthesis. Sometimes, however, the plant can isolate carbohydrate by modifying its growth. Thus, detached potato leaves without roots on their petioles produce swellings at the bases of the leaflets where the cells are filled with starch (Humphries, unpublished). Rooted bean leaves use carbohydrate in extension growth of palisade cells (Humphries, 1967 loc. cit.). Dickerson and Edelman (1966) observed that, when tuber initials are removed from plants of *Helianthus tuberosum* grown in short days, the fibrous roots produce tuber-like swellings filled with fructosans.

Little is known about the way in which accumulation of carbohydrate slows down photosynthesis. Possibly more than one mechanism exists. The simplest would be by stomatal control, with stomata closing when sugar contents increase above a certain value. Lee (1965) reported that large amounts of sugar in tobacco leaves closed the stomata, but in most plants slowing of photosynthesis when sinks are lacking seems unrelated to stomatal closing. Wilson (loc. cit.) suggested three ways in which accumulated assimilates depress assimilation. (1) a mass action effect; (2) enzymatic control by the phenomenon of regression or "end product inhibition"; (3) physical obstruction of diffusion or light transmission by accumulation of assimilates in cytoplasm or chloroplast.

The mechanism by which sinks such as growing points, storage organs or fruits accumulate substances is still unknown— it is not definite whether storage organs are passive acceptors of carbohydrate or whether these organs actively pull substances towards them. Watson and Petrie (1940) interpreted the mobilising role of the apex and flowers as a sink into which nutrients flow, but evidence is increasing that the processes of accumulation is under hormonal control. Various authors have demonstrated that applying growth substances to plant organs initiate mobilisation: thus, Marre and Murneek (1953) found very similar accumulation of carbohydrate both in kind and amount in tomato ovaries whether these were fertilised with pollen or treated with auxin. They concluded that auxin acted by mobilising reserves from other regions of the plant. Similarly, Davies and Wareing (1965) showed that, when IAA was applied to decapitated shoots of *Pisum* or disbudded shoots of *Populus*, ^{32}P moved towards the treated region. Accumulation of ^{32}P by the decapitated second internode of *Phaseolus vulgaris* was stimulated by applying IAA and further increased by kinetin or gibberellic acid (Seth and Wareing, 1964). The strongest hormonal mobilisers are the kinins (e.g. Engelbrecht and Mothes, 1961; Mothes, Engelbrecht and Schutte, 1961) and it is probably significant that all fruits so far examined contain kinins (see Crane, 1964), which are not necessarily concerned only with cell division. However, no direct relationship between the ability of fruits to accumulate substances and the content of kinins has yet been demonstrated but a further resemblance between natural accumulation and kinin-induced accumulation is that they are both unselective: for instance, -α-aminobutyric acid travels to the kinin-treated region of a leaf but is not used. Phosphate, sulphate and glucose also accumulate in such leaves (Englebrecht, 1961). Similarly, miscellaneous substances accumulate in fruits and seeds which have no apparent metabolic function. The phenomenon noticed by Turner and Bidwell (1965) that fluctuations in photosynthesis of a leaf seemed to be correlated with appearance of buds may be connected with hormone-controlled translocation. They also found spraying leaves with IAA increased rate of photosynthesis after 30 minutes; the effect did not reflect stomatal response. When IAA was sprayed on to a bean leaflet, CO_2 assimilation in neighbouring leaflets increased. (Bidwell and Turner, 1966). Coulombe and Paquin (1959) obtained a similar response with gibberellic acid.

Knowledge of how storage organs mobilise reserves is of obvious practical importance, because by influencing the amount of substance flowing to a sink, it might be possible to increase photosynthetic efficiency. Varietal differences might be related to the endogenous hormone content of the sink organ.

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THE USE OF ROOTED LEAVES AND GRAFTED PLANTS FOR THE STUDY OF CARBOHYDRATE METABOLISM IN *SWEET POTATO*

— *by* —

L. A. Wilson*

Introduction

In a review of some of the physiological determinants of tuber yield in different sweet potato varieties, (Wilson 1967) it became evident that the direction of photosynthate to tubers was perhaps more important as a determinant of tuber yield than the total amount of dry matter produced by the plant. The direction of photosynthate to tubers, (organs of perennation) was considered to be an attribute of plant morphogenesis, as opposed to the photosynthetic attributes of the plant which were more related to total dry matter production. Final tuber yield was considered to be the end result of a series of morphogenetic changes associated with the direction of photosynthate to sinks connected with leaf production, leaf expansion, lateral bud development, decreasing specific leaf area and, at a certain critical point in the sweet potato life cycle, the tuber sink. The final balance established between the tuber sink and the several alternative leaf sinks at harvest time, is therefore, the ultimate determinant of yield in sweet potato species.

Three aspects of carbohydrate metabolism are involved in effecting these morphogenetic changes.

(a) carbohydrate production

(b) carbohydrate transport

(c) carbohydrate immobilization in tuber tissue, thus creating a sink capable of accepting more transport carbohydrates

Carbohydrate transport and carbohydrate immobilisation in the tuber sink, are considered to be more important factors affecting tuber yield than carbohydrate production per se and these factors are now further examined, using plant models, conveniently referred to here as photomodels.

Materials and Methods

Definition of Phytomodels

A phytomodel, is here defined as a modified plant or plant organ, which has both a root system and a photosynthetic surface and is therefore an independant autotrophic, metabolic unit, capable of integrated growth by cell division cell expansion, and cell differentiation.

The design and use of phytomodels e.g. rooted leaves, petioles and laminae and grafted plants, provide simple and easy to handle mechanisms for the study of physiological pathological and biochemical problems. In such phytomodels, internal and external factors in the plant environment can be varied independently, on a scale not possible in conventional studies using intact plants. Phytomodels

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are also considered to have a wider application than tissue cultures, which are neither independent nor autotrophic metabolic units, nor do tissue cultures approximate any morphogenetic condition in the intact plant. Phytomodels are also preferred to systems using leaf discs or tuber discs, which are of limited viability and uncertain metabolic significance.

The use of what is here defined as a phytomodel is not new and such systems have been previously used in physiological studies. Thus Thorne (1962) described the use of sugar beet/spinach beet grafts for examination of factors affecting yield differences between these two species. Humphries and Thorne (1961), (1963), (1964) also used rooted dwarf French bean leaves for the assessment of the size of the root sink on leaf photosynthesis.

Attention is drawn, however, to the wider application of such phytomodels, provided that they can be calibrated against biochemical and physiological changes known to occur in the intact plant. Preliminary experiments here described are concerned with the calibration of rooted leaf and grafted plant phytomodels of several sweet potato varieties, against changes in dry matter content associated with carbohydrate transport and immobilization, known to occur in the intact sweet potato plant. Similar phytomodels are also being used in this laboratory for the study of physiological and biochemical aspects of intervarietal susceptibility to the pathogenic fungus, *Ceratocystis fimbriata*, responsible for the *Ceratostomella* wilt disease in cacao.

Rooting of Sweet Potato Leaves

Sweet potato leaves can be rooted by immersing their petioles in moist sand or in water, and keeping the leaves in a humid atmosphere. Rooting takes place in from five to ten days. Growth substances e.g. indole acetic acid (IAA), indole butyric acid (IBA) and naphthyl — acetic acid (NAA) all increase the rapidity with which root initiation takes place, and the number of root initials formed. IAA, however, tends to increase the length of growing root whilst IBA and NAA tend to induce the production of short thick roots. Rooting also varies with the age and variety of the leaf used. Mature leaves root more easily than young leaves. Leaves from pigmented varieties of sweet potato also tend to root more easily than leaves from non pigmented varieties.

In varieties in which rooting takes place with difficulty, rooting is facilitated by allowing stem cuttings with leaves attached, to stand in a humid propagation bin for two to three days. After this period of incubation, lateral buds and roots develop at each node, and root initials may already be formed at the base of leaf petioles. Such leaves, with or without root initials, root easily when severed and placed in water. In the present experiments, mature sweet potato leaves were rooted without auxin treatment, either by simply dipping the roots in water in a suitable container (100 ml conical flask) or by so doing after a preliminary incubation period in a propagation bin as described above. Leaves from the following sweet potato varieties collected from Mr. B. Williams of the Faculty of Agriculture, University of the West Indies, (St. Augustine) have been successfully rooted. 049; C9; C104; A138; F2; 01/59; R38; 14/60; A26/16.

Grafting of Sweet Potato Cuttings

Effective graft unions of sweet potato cuttings from different varieties can be made by cleft grafting of cuttings from the respective varieties. (Wilson and Dawlet 1967). Cuttings used for grafting, should be about six to ten inches in length including at least three nodes and should be of similar diameters. Once joined together by a typical cleft graft and secured with polythene grafting tape, the stem cutting needed as the root stock is defoliated and placed in a sand/coconut fibre dust rooting medium, in a propagating bin.

Rooting of the root stock, healing of the graft union and development of the lateral buds on the scion, all take place within seven days. Removal of three quarters of the laminae of leaves on the scion end of the graft, facilitates the growth of the grafted cuttings.

Satisfactory results can also be obtained by placing graft unions to root in a suitable container of water, under shaded conditions in the greenhouse. Suitable graft unions can be transferred directly to experimental containers in the greenhouse for further growth and study. The sweet potato varieties 049, R38 and C9 have been successfully grafted by this method in all possible combinations.

Rooted leaves

Wilson (1967) pointed out that one of the factors associated with reduced yield in staked sweet potato plants (var. A138) in the absence of applied nitrogen fertiliser (Chapman and Cowling 1956) was a relative decrease in specific leaf area in the 7th—9th weeks after planting. This decrease in specific leaf area was coincident with an increase in specific leaf area in plants supplied with nitrogen fertiliser. Increase in specific leaf area, in N-fertilised plants took place immediately prior to a critical period of N-stimulated increase in tuber dry weight, 9th—11th week). Decrease in specific leaf area in the absence of applied nitrogen fertiliser was interpreted to mean that carbohydrates were stored in the alternative leaf sink because of the restriction in the capacity of tubers to accept translocated carbohydrates, during the 7th—9th weeks of growth. Carbohydrates have been shown to accumulate in the leaves of nitrogen deficient sweet potato plants. (Wilson 1964). Accordingly, the rooted leaf phytomodel was examined in order to find out whether a similar alternative accumulation of carbohydrates in the leaf could be induced, under conditions of a restricted nitrogen supply. Such calibration of a process known to occur in the intact plant is thought to be a necessary prerequisite for investigation of the process using a phytomodel.

Experimental

Rooted sweet potato leaves (var. C9) were grown in one half strength culture solutions (Hewitt 1965) for one week after rooting and then transferred to solutions containing plus nitrogen and minus nitrogen nutrient treatments. After selected intervals of growth, rooted leaves were completely destarched by being placed in a dark cupboard overnight. Destarched leaves were then tested for starch, exposed to sunlight and the time taken for starch to accumulate in leaves measured. Starch accumulation was estimated by first extracting chlorophyll from leaf discs (0.5 cm diameter) taken from three rooted leaves per treatment, and testing these discs for starch with iodine in potassium iodide. Colours ranging in intensity from yellow to brown to black were developed, according to the amount of starch present in leaf discs. The time taken to develop a black colour was recorded as the time necessary for maximum accumulation of starch in leaves.

Results

Relevant results are given in Table 1 below.

Table I.
Starch Accumulation in Destarched Sweet Potato Rooted Leaves (var. C9)

Treatment	Time to Max. Starch Accumulation 1 wk growth	3 wks growth	Root D. Wt. at 3 weeks	Specific leaf area at 3 weeks	% Total N in lamina
+ N Discs	12 mins.	15 mins.	0.75 gm.	7.9	3.25%
− N Discs	5 mins.	0 mins.	0.34 gm.	5.6	2.4%

The data (Table 1) indicated the rate of starch accumulation was more than twice as fast in nitrogen deficient leaves compared with nitrogen sufficient leaves after one week of growth. At this time, there was no observable difference in the appearance of leaves from different treatments, and the recorded root dry weights were also similar (+N-0.45 gm: - N-0.40 gm).

After three weeks of growth, leaves growing in minus nitrogen solutions could not be destarched even after seventy-two hours in the dark. These leaves had apparently attained a condition of permanent starch saturation, which was associated with cessation of the growth of their roots, the only major carbohydrate sink. At the end of the three weeks of growth, laminae of the minus nitrogen rooted leaves showed only mild symptoms of nitrogen deficiency (interveinal chlorosis). The dry weight of roots from these plants and the percentage nitrogen in their laminae were however reduced compared with leaves grown in plus nitrogen solutions. Petiole slices also gave a more positive test for starch than similar slices from plus nitrogen leaves.

Changes in carbohydrate distribution in the absence of nitrogen supply also resulted in a 40% decrease in the specific leaf area of minus nitrogen rooted leaves compared with plus nitrogen leaves.

Effects of nitrogen deficiency and deficiences of other plant nutrients on the carbohydrate saturation point of rooted leaves are being examined in eight other varieties of sweet potato. Preliminary results indicate that a pattern of carbohydrate saturation similar to that obtained with nitrogen deficiency, occurs in sulphur deficient rooted leaves. With calcium deficiency no carbohydrate accumulation could be demonstrated in petiole slices. The carbohydrate saturation point was not attained in iron deficient rooted leaves, nor did even mild symptoms of iron deficiency develop in these leaves.

Discussion

Carbohydrate accumulation took place in the laminae of nitrogen deficient rooted leaves and was accompanied by decreases in specific leaf area. Decreases in specific leaf area and leaf area ratio have been found to be associated with early stimulation in sweet potato tuber bulking due to limited nitrogen supply (Wilson 1964) and with decreases in final yield in staked sweet potato plants in the absence of applied nitrogen fertiliser.

Starch accumulation has also been found to take place in the leaves of nitrogen deficient sweet potato plants grown in sand culture by the author. The rooted leaf provides a simple mechanism for examining the relative distribution of photosynthate between the root sink and the alternative leaf sink as a function of root growth and nutrient supply. The absence of accepted sources of auxin supply e.g. stem apex and lateral buds, from the rooted leaf phytomodel, allows for the study of effects of various levels of externally applied auxins on the processes involved in carbohydrate mobilization and accumulation.

Grafted Sweet Potato Plants

It was suggested (Wilson 1967) that perhaps the most important factor affecting intervarietal differences in sweet potato yield was the inherent tendency of different varieties to tuberize. A similar conclusion was also reached by Ivins and Bremner (1965) for Solanum potatoes. The rate of tuber bulking associated with this basic tendency, however, was thought by the formed author to be a function of the capacity of tubers to accept, metabolise and store carbohydrates, at different stages in their growth cycle. This interpretation of tuber bulking pre- supposed that the factors governing the rate of this process were morphogenetic rather than photosynthetic, and evidence in favour of this interpretation was given (Wilson 1967).

The emphasis given to considerations of net assimilation rates leaf area indices and leaf area duration, by Acland (1963), Cowling (1964) and Chapman and Cowling (1965) and to total leaf area as related to nitrogen response Tsunoda (1965) implied that these authors considered the total amount of photosynthate produced by the plant to be the more important determinant of sweet potato tuber yield. References to effects of mutual shading on tuber yield also embodied the same implication.

Tsuno and Fujise (1965) classified sweet potato varieties according to photosynthetic activity into:—

(a) leaf area types, with high leaf areas and low photosynthetic rates per unit leaf area, and

(b) net assimilation types, with low leaf areas and high photosynthetic rates per unit leaf area.

These authors further demonstrated that there existed in these two types, an apparently compensating photosynthetic mechanism. This mechanism resulted in similar rates of photosynthesis per plant, midway in the growth cycle of the types examined. The relevant question is whether the rate of photosynthesis was relatively increased in the low leaf area type due to increased tuber bulking, a process shown to take place by Tsuno and Fujise, or was photosynthesis relatively reduced by mutual shading in the high leaf area type. The former effect is considered to be morphogenetic and the latter, photosynthetic.

It should be mentioned at this point, that the inverse relationship between leaf area index and net assimilation rate shown to exist in sugar beet and kale by Watson (1958) could be demonstrated neither for a wide range of sweet potato varieties of greatly differing leaf area indicies (Acland 1963) nor for a single variety of sweet potato under staked and unstaked conditions of growth (Chapman and Cowling 1965).

It was in order to attempt a separation of the above mentioned morphogenetic effects from photosynthetic effects as the primary determinent of sweet potato yield, that grafted sweet potato phytomodels were designed.

Accordingly, grafts were made of all possible combinations of root stocks and scions between sweet potato varieties of:

(a) different tendencies to tuberize

(b) different leaf areas

(c) different leaf shapes, which allowed for variations in the amount of mutual shading associated with leaf development. The photosynthetic effect is also being examined by subjecting the grafted plants to different light regimes.

The sweet potato varieties initially used were:—

(i) 049 — (high yielding - high leaf area - entire leaf margin).

(ii) C9 — (high yielding - low leaf area - entire leaf margin).

(iii) R38 — (low yielding - low leaf area - deeply lobed leaf margin).

Experimental

Plants of the three varieties were joined by cleft grafts in the following combinations, where the first mentioned variety is the scion and the second the root stock.

049/R38	R38/049	C9/R38
049/C9	R38/C9	C9/049
049/049	R38/R38	C9/C9

In addition to these grafted phytomodels, intact plants of the three varieties were included in the experiment and all plants were subjected to two light regimes.—

(a) full sunlight

(b) 60% sunlight achieved by shading with saran netting

Three plants per treatment were grown in four-gallon containers containing soil in the greenhouse. No fertiliser treatments were applied to the plants.

Results

Preliminary results reported here are concerned mainly with the calibration of the growth pattern of grafted sweet potato phytomodels against intact plants. Effects of light intensity and graft union on leaf number and lateral shoot production after two months of growth are given in Table II.

The results (Table II) indicated that intact plants produced leaves at a faster rate than grafted plants, due no doubt to growth restriction associated with the healing of the graft union. Grafts containing similar root stocks and scions also consistently produced leaves at a more rapid rate than grafts of root stocks and scions from different varieties.

Grafts containing R38 scions tended to produce more leaves than those containing 049 and C9 scions respectively. This trend was similar to that which obtained in intact plants

Table II. Effects of light intensity and graft union on leaf number and lateral shoot production in several sweet potato phytomodels

	Leaf number		No. of Lateral Shoots	
Graft	Full Sunlight	60% Sunlight	Full Sunlight	60% Sunlight
049/R38	74	78	3.6	5.0
049/C9	80	73	4.5	4.5
049/049	96	112	3.0	5.2
049 (intact plants)	116	121	3.3	4.1
C9/R38	51	61	4.5	5.0
C9/049	56	76	4.2	5.9
C9/C9	99	98	6.5	5.5
C9 (intact plants)	108	111	6.1	6.0
R38/049	81	59	6.5	5.5
R38/C9	92	65	5.5	5.1
R38/R38	122	94	6.2	7.5
R38 (intact plants)	131	124	6.3	6.1

Effects of light intensity were variable, but there seemed to be an increased production of leaves in full sunlight in grafts with R38 scions, which was greater than a similar effect observed in intact R38 plants.

On the contrary, full sunlight seemed to decrease the number of leaves produced in plants with C9 tops, particularly those of C9/R38 and C9/049 phytomodels. This effect was not observed in intact C9 plants. Leaf number was not greatly affected by light intensity in models with 049 scions.

Effects of graft union and light intensity on lateral shoot development were variable, and did not show any definite trend, except perhaps than in plants with 049 tops, lateral shoot production took place more slowly than in other phytomodels and intact plants.

Results of tuber yield after eight weeks of growth (Table III) indicated that yield (tuber fresh weight) was in all cases reduced, and tuberization often completely suppressed under shade conditions. These yield reduction were associated with increases in specific leaf area (average of ten mature leaves) at the lower light intensity. In models with 049 scions, tuber yields was considerably reduced compared with intact plants. Tuber yield of 049/049 models was double that 049/C9 models. Tuberization was suppressed in 049/R38 models even infull sunlight. The increased tendency to tuberize showed by the 049 rootstock was further demonstrated by the increased yield of the C9/049 model over both the C9/C9 model and intact plants of C9. It was perhaps significant that leaf production in the C9/049 phytomodel was considerably reduced compared with the C9/C9 model and C9 intact plants. Yields of R38/049 models were also increased compared with R38/R38 models and intact plants of R38. C9 was not as effective in increasing tuber yield in reciprocal grafts as was 049. Results for the comparison of final yields with leaf area ratio and specific leaf area, based on total leaf area measurements are not yet available.

Table III. Effects of light intensity and graft union on leaf area/leaf weight ratios and tuber yield after eight weeks of growth in several sweet potato phytomodels.

Graft	Tuber F. Wt. at 8 wks		Leaf Area/Leaf D. Wt. of 10 mature leaves	
	Full Sunlight	60% Sunlight	Full Sunlight	60% Sunlight
049/R38	—	—	6.7	10.5
049/C9	8	—	6.5	10.7
049/049	17	16	4.5	6.3
049 (intact plants)	105	41	6.6	8.4
C9/R38	—	—	13.2	14.1
C9/049	132	24	5.2	8.3
C9/C9	80	—	10.0	6.6
C9 (intact plants)	98	12	9.6	12.2
R38/049	47	—	11.1	12.2
R38/C9	—	—	11.1	14.1
R38/R38	13	—	8.8	16.6
R38 (intact plants)	27	—	10.4	14.5

Discussion

It would appear from this preliminary experiment that tuber development in the sweet potato varieties examined was a function of their tendencies to tuberize. Further, this tendency was associated with characteristics of the sweet potato root stock and could be transferred to another variety by reciprocal grafting. The calibration of reciprocal graft phytomodels against intact plants, indicated that leaf development was somewhat affected by the grafting process but that this effect did not preclude the development of what appeared to be real differences in the tendencies of different varieties to tuberize, in models examined.

Summary and Future Work

Two systems conveniently called phytomodels, rooted leaves and reciprocal grafts of different sweet potato varieties have been described and their use in the study of carbohydrate mobilization and carbohydrate storage, in the sweet potato discussed.

Preliminary experiments on the calibration of the phytomodels against growth changes known to occur in intact sweet potato plants have been described.

Such calibration is an important pre-requisite in the use of models for the study of factors affecting tuber development. This is so, because tuber development itself, is interpreted as the expression of a series of morphogenetic changes associated with the direction of photosynthate to the tuber sink. Since these changes are themselves not completely understood, the precise nature of the process examined with a phytomodel must be defined and its significance in relation to the intact plant established.

Rooted leaves of different varieties of sweet potato are being used for studying the distribution of photosynthate between the root sink and alternative leaf sink. Effects of nitrogen nutrition on this distribution are being particularly examined because of the variable yield responses of sweet potato varieties to nitrogen fertilization.

Reciprocal grafts are being used for examining intervarietal differences in the capacity for tuberization in the sweet potato, because previous efforts to relate tuber yield to foliage characteristics have met with limited success. Indications are that intervarietal differences in tuber yield are related to tuber growth.

The ultimate aim of this work is to find out the factors of primary importance in tuber growth. On this subject, attention is drawn to the fact that tuber cells must first be formed before they can act as a tuber sink. Expansion of these cells once formed is also a pre-requisite for the increase in size of the tuber sink with development. Factors affecting tuber cell division and cell expansion may be independent of those affecting carbohydrate production, but they certainly are important as determinants of the size of the tuber sink.

Effects of high levels of nitrogen supply (Wilson 1964) and observations on the effect of low light intensity on the restriction of tuber growth, suggested that factors affecting tuber growth were related to the morphogenetic condition of the sweet potato plant sensu Evens and Hughes (1961) and Whitehead and Myerscough (1962). The direct effect of exposure to light on the restriction of tuber development (Tsuno and Fujise 1965) also suggested that a light dependent mechanism in the tubers themselves is also a factor affecting tuber growth.

A number of regulatory functions have been ascribed to indole acetic acid in plants. Recent work suggested that auxins might also be involved in tuber growth. Thus, high levels of entodenous hormones have been shown to mediate in nitrogen increased shoot/root ratios by Wilkinson and Ohlrogge (1964). Strong evidence suggesting that the breaking of lateral bud dormancy was coincident with auxin release by the growing bud has also been supplied by Turner and Bidwell (1965). Wilson (1964) showed that nitrogen induced lateral shoot development was inversely related to tuber growth, in sweet potato plants grown in sand culture. Auxins released by lateral bud development might therefore have resulted in inhibitory levels of auxin in sweet potato roots. Rapid early growth of sweet potato tubers at low levels of nitrogen supply, in the same experiments, might simply be the reverse of this process.

Indole acetic acid has also recently been shown to control cellulase activity in the apices of etiolated pea seedlings by Fan Der-Fong and Maclachlan (1966) and these authors suggested that cellulase action played an essential role in a variety of growth processes, particularly lateral cell expansion. On the other hand, Lnewnberg (1965) found that citric acid promoted IAA destruction in tobacco callus tissue, with a concommitant inhibition of bud formation. Destruction of IAA was apparently mediated by stimulation of IAA oxidase activity. Citric acid has also been found to induce loss of rigidity in Solanum potato tuber slices, associated with depression of oxygen uptake over the period when the tissue became flaccid. (Somers 1965).

One of the prerequisites for cell expansion is cell turgidity. It is suggested, therefore, that endogenous levels of auxins and mechanisms controlling these levels, might be responsible for intervarietal differences in tendencies to tuberize in sweet potato. Accordingly, it is proposed to use phytomodels to examine the effects of citric acid and other organic acids on cellulase and IAA oxidase activity as related to cell expansion in root cells of rooted leaves and tuber cells of grafted sweet potato plants. Precalibration of these phytomodels against processes associated with intervarietal differences in photosynthate distribution in the sweet potato, could lead to valuable information on the exact nature of the morphogenetic changes associated with tuber development.

Apart from this fundamental objective, grafted sweet potato phytomodels could provide an immediate answer to the plant breeder, with respect to the capacity for tuberization of new varieties. Such a use for these phytomodels is suggested by the increased tuberization of C9/049 and R38/049 reciprocal grafts over C9 and R38 intact plants. The capacity for increasing tuberization in models with C9 and R38 scions could be taken as a measure of the tendency for tuberization of a particular variety.

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Mr. Williams :

The artificial synthesis of experimental systems such as rooted leaves seems to be an experimental approach of great popularity among biochemists and plant physiologists. It is apparent to me that such systems involve biochemical and physical manipulations, which could just possibly not be representative of relationships as they exist among plants in coenocytic contact with the total environment. The justification of your methodology would be to accumulate a background of knowledge exploring the degree to which findings in the artificial system correlate with actual processes in the living plants in vivo.

Could you tell me whether in your own work you find it necessary to document your findings against the background of the living plant, or do you consider that your methodology is already established?

I would like to make reference to your work on CCC in relation to leaf area, and tuberisation. There are suggestions from work done at this university by Spence and Haynes that on the basis of field experiments, sweet potatoes respond to manipulation of leaf area, for example by adding higher levels of nitrogen to the soil. It responds to this sort of manipulation, by delaying — roughly in proportion to the degree to which the leaf area is increased — the time required for them to attain maturity. I think this is what Prof. Milthorpe has termed ontogenetic drift.

Dr. Humphries :

The plant physiologist is up against a very difficult problem in dealing with the whole intact plant, and anyway if we can get a simple system to work on, to give us some idea of the processes that take place in the plant, it is very welcome. This is why we introduced this rooted leaf system. It is, in fact, not such a simple system as we hoped it would be, because, as Dr. Wilson points out, the lamina itself, as well as the root system, acts as a considerable sink for the carbohydrate, and you cannot really say that this is just a simple sort of sink relation.

Dr. Wilson :

With reference to Mr. Williams' question, a major consideration of ours has been the calibration of processes in systems which we like to call phyto-models, against the same processes, as they occur in the intact plant. For example, carbohydrate accumulation is known to take place in the intact plant with nitrogen deficiency. Carbohydrate accumulation also occurred in the rooted leaf. It is possible, therefore, to study carbohydrate accumulation, using the rooted leaf, provided this process could be calibrated against the parallel process in the intact plant. We have measured the rate of leaf production in intact plants compared with that in grafted plants. In the grafted plants, in fact, leaf production was reduced, compared with the intact plants. But this did not preclude the appearance of what we felt were real effects of different scions and root stocks on tuberisation.

Dr. Sidrak :

Are there any known factors, externally or internally, which affect the kinin production in any of the plant studies?

Dr. Humphries :

I think, just to summarize our knowledge on this, all that is being done with the natural system so far, is that fruits have been taken and extracted, and the kinin content estimated. Very little is known about the development of the kinins during the development of the fruit, and we know practically nothing about its determining factors.

Dr. De Gras :

You have said that when you observed shortening of the stems, the shortening could be interpreted as a reduction of the sink but is not there also an increase in the part of the leaf which reached compensation point?

Dr. Humphries :

This is true, and we thought first of all that this was a possibility, but when we did the experiment with potato, where the stem is also shortened, and the leaves more crowded, we did in fact, get an increase in the net assimilation rate, so we thought that probably the stem shortening was the chief factor.

Dr. Spence :

In view of the importance attached to potassium by Dr. Fujise, could Dr. Wilson or Prof. Humphries state whether they have taken this into account in their measurements of the efficiency of their models.

Dr. Wilson :

Yes, to some extent. We have looked not only at nitrogen deficiency using the rooted leaf system, but we have looked at iron deficiency, potassium deficiency, calcium deficiency, sulphur deficiency. The pattern of carbohydrate accumulation is quite similar with nitrogen and sulphur deficiency. In other words a carbohydrate saturation point was arrived at, in which carbohydrate accumulated in the laminae, petioles and in the roots.

With calcium deficiency, carbohydrates tended to accumulate in the laminae. We could not demonstrate high levels of carbohydrate accumulation in the petioles. This result, of course, is based only on a qualitative assessment of carbohydrate status of tissues by the iodine test for starch.

With potassium deficiency, the results were not conclusive in that replicates gave different results. The model rooted leaf took a very long time to become potassium deficient, but when it seemed so, as indicated by the potassium content of the laminae, then the pattern of carbohydrate accumulation was rather erratic. Sometimes carbohydrates accumulated in the leaves, sometimes in the petioles, and sometimes in the roots.

With iron deficiency there was never any marked accumulation of carbohydrates. This is perhaps because, either iron deficiency reduces the rate of photosynthesis dramatically or that we hadn't produced symptoms or conditions of iron deficiencies in the rooted leaf.

Dr. Humphries :

We have not done any experiments where we varied the potassium, we only varied the nitrogen.

Dr. Royes :

I am very interested in Dr. Wilson's grafting experiments. It is known that O49 is a higher yielder or a little bit higher than C9 and that the difference in foliage is considerable. Is it possible that with the C9 scion, O49 graft, the higher production may be due either to the higher efficiency or greater leaf area of O49, and possibly the greater sink potential of the C9 scion, and do we have any method that would help a breeder to measure the sink potential?

Dr. Wilson :

I made a suggestion in the last sentence of my paper, that grafted plants could perhaps be used for determining the capacity for tuberisation of an individual variety. This suggestion was made because grafted plants highlighted only after eight weeks of growth, the already well known difference in yield potential between O49 and C9 and this, is at the time when the maximum weight of the tuber was only 132 grams. So, perhaps a calibration, with reference to Mr. Williams' question, could be devised whereby the yield potential of a new variety, could be determined by the capacity of its root stock to tuberize effectively when joined to the scion of a low yielding variety e.g. B. 38. This approach perhaps, may give results, but calibration of the processes involved must be carefully done before such experiments can be attempted.

Dr. Humphries :

I do not think that there is any method at the moment of estimating sink potential, but if we can establish that sinks are dependent on certain growth substances, then perhaps we can get somewhere near.

Dr. Carr :

I would like to ask Dr. Humphries whether he knows of any work on carrots, with regard to source and sink relationships, and secondly, whether he thinks that there are any compounds or other treatments which may induce early formation of a sink in plants like carrots or sugar beet.

Dr. Humphries :

I cannot recall, at the moment, any work on carrots. I think one reason why carrots are so very little worked on is the difficulty of measuring its leaf area. I do not know whether Prof. Milthorpe could answer this question

Prof. Milthorpe :

No. I do not think that one can change the time of initiation of root growth in sugar beet, or possibly in carrots very much. I think that these are very fixed effects, and Dr. Humphries' slides where he looked at the effect of CCC on sugar-beet emphasises this

PLANT NUTRIENT DEFICIENCIES AND RELATED TISSUE COMPOSITION OF TANNIA (XANTHOSOMA SAGITTIFOLIUM)

— by —

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Deficiency symptoms have been described for tropical plantation crops but for many important food crops such symptoms have yet to be described. A series of studies is now underway to produce and record the symptoms of deficiency of food crops of importance to the West Indies. The results of studies on Pigeon Pea (Gungo pea) *Cajanus cajan* (Nichols 1964) and Sweet potato *Ipomoea batatas* (Spence and Ahmad 1967) have already been published.

This paper deals with the symptoms produced by lack of the major plant nutrients; nitrogen, sulphur, phosphorus, calcium, potassium, magnesium and iron on tannia, *Xanthosoma saggitifolium*. The authors have not been able to find any previous record in the literature of deficiency symptoms in this crop.

MATERIALS AND METHODS

Culture technique.

The sand culture technique used was modified from methods reported by Hewitt (1952) and was described in detail in a previous paper (Spence and Ahmad 1967). It consisted essentially of a series of clay pots, 20 cm. in diameter, coated inside with bituminous paint and filled with acid washed (10% hydrochloric acid) beach sand. Watering with nutrient solution was accomplished automatically by means of an air pressure pump controlled by a time switch. The solution was forced by air pressure from winchester flasks under each pot up a polythene tube passing through the centre of the pot, so that it was sprayed on to the surface of the sand.

The nutrient solutions were taken from Machlis and Torrey (1959) and the concentrations of the major elements in the control solution were (in milligram equivalents per litre of ions or radicals): Ca 10.0, K 6.0; Mg 4.0; NO_3 15; PO_4 3.0; SO_4 4.0. In the deficient solutions Na replaced K, Ca and Mg; and Cl replaced SO_4, NO_3 and PO_4 at equivalent concentrations. Plants were obtained by placing ½ inch thick slices of mother corms in sand in a plant propagator and allowing the buds to grow. After sprouting of the buds the sprouts were removed from the corm slices and kept in sand until they were properly established as independent plants. Watering was carried out with distilled water only. The plants were then transplanted to the sand culture pots and watered with the appropriate nutrient solutions.

Each treatment was replicated three times and there was one plant per pot.

Preparation and chemical analysis of tissue

After eight weeks symptoms had developed markedly and the plants were harvested for tissue analysis.

At harvest, sand was washed off the root systems in the greenhouse and the whole plants were brought to the laboratory for further preparation. Leaves and petioles, roots and corms were separated, prior to analysis. Samples were bulked for each treatment and washed in one percent detergent solution (Teepol) and then rinsed successively in three lots of distilled water, the water being renewed after every five washings. Samples were then dried at 80°C. and ground in a stainless steel micro-hammer mill. Fresh weight and dry weight of the separate parts were recorded.

For total nitrogen and phorphorus determinations 0.1000 gm of the ground sample was digested with sulphuric acid and hydrogen peroxide; nitrogen was estimated by the micro-kjeldahl method and phorphorus by the molybdo-vanadate method (Jackson, 1960). Potassium, calcium, magnesium and iron were determined on samples ashed at 450°C.; the soluble residue was taken up with dilute hydrochloric acid and the solution was analysed for the various elements. Potassium was determined by the flame photometer, calcium and magnesium by the versenate method and iron by the thiocyanate method (Jackson 1960). Sulphur was determined on samples pre-treated with a 10 percent solution of magnesium nitrate and ashed at 450°C. Sulphur was precipitated as barium sulphate and determined gravimetrically

RESULTS AND DISCUSSION

Tissue Analysis

The tissue analysis was not intended as a guide to nutritional status but rather as a check on the symptoms in relation to shortage of particular elements. However attention is drawn to certain trends which may provide interest for further study.

Results of tissue analysis of leaves and petioles, roots and corms are presented in Table 1.

Nitrogen, phosphorus and potassium occurred in lowest concentration in the corms. Calcium, magnesium, sulphur and iron were generally highest in the roots with leaves and petioles next.

Minus nitrogen was associated with low values for total nitrogen throughout the plant. This treatment resulted in low values for phosphorus and calcium in the corms and increased accumulation of sulphur in the leaves and petioles.

Minus phosphorus resulted in low tissue content of this element particularly for tubers. Nitrogen content was depressed for the leaves and petioles and corms but not for roots. Calcium was also depressed throughout the plant but iron accumulated in the roots.

Minus potassium resulted in low levels of potassium throughout the plant. This treatment led to high levels of calcium and magnesium and an accumulation of iron in the roots and corms. The relatively high level of potassium in this treatment (2.5 percent) and its association with severe deficiency symptoms indicate a high requirement of this crop for this nutrient.

No calcium led to low levels of calcium in the whole plant, but particularly in the roots and corms. High levels of nitrogen, phosphorus and potassium were associated with lack of this nutrient in all parts of the plant. Sulphur accumulated in the roots and to a lesser extent in the corm.

Minus magnesium resulted in low levels of magnesium throughout the plant. Accumulation of phosphorus, potassium and calcium took place in the leaves and petioles and corms but not in the roots.

Lack of sulphur resulted in low levels of sulphur in the entire plant. Considerable accumulation of potassium took place in the leaves and petioles. Phosphorus reached a high level in this treatment for leaves and petioles and roots. Low values for iron occurred in the leaves and petioles and corms

The no iron treatment was associated with low levels of iron in the plant, and particularly in the leaves. This treatment resulted in an increase in nitrogen in the leaves and petioles and roots but a slight depression in the corms.

It should be noted that in this plant there is a high proportion of petiole to lamina and this may be responsible for certain features of the tissue analysis data.

The data presented for a field sample of tannia leaf and petiole showing severe magnesium deficiency symptoms is of some interest here. This soil (Brasso Clay, Trinidad) has a low level of available magnesium and citrus growing on it shows magnesium deficiency symptoms associated with low levels of magnesium in the tissues (C.C. Weir, Peronal Communication). The level of magnesium in the tannia tissue was as low as for the minus magnesium treatment in the pot experiments.

Another interesting feature of the data was the very high levels of potassium and phosphorus especially in the leaves, petioles, and roots where these elements had been supplied. A high level of potassium was also noted in the sample of petioles and leaves taken from the field (Table 1).

Table I

Results of Chemical analysis of leaves and petioles, roots and corms of the tannia plant

Treatment	N	P	K	Ca	Mg	S	Fe
			percent				(ppm)
			Leaves and Petioles				
— N	1.81	0.59	9.00	1.17	0.32	0.53	204
— P	2.85	0.31	9.40	1.44	0.34	0.15	227
— K	5.24	1.80	2.50	1.98	0.72	0.28	190
— Ca	4.22	0.69	12.40	0.55	0.56	0.26	256
— Mg	3.68	0.72	11.40	2.00	0.07	0.23	176
— S	3.85	1.27	14.20	1.60	0.58	0.13	100
— Fe	3.89	0.49	9.80	2.51	0.26	0.25	45
Control	3.57	0.47	8.90	1.97	0.20	0.20	152
*Field Sample	3.73	0.45	9.00	2.00	0.09	0.18	152
			Roots				
— N	1.48	0.69	9.38	1.92	2.00	0.12	550
— P	3.58	0.20	7.80	1.30	0.77	0.16	960
— K	3.22	0.53	1.20	3.40	1.32	0.49	800
— Ca	3.32	0.85	9.00	0.28	3.12	0.95	360
— Mg	3.36	0.59	8.40	1.32	0.22	0.35	696
— S	3.86	1.11	8.63	2.40	1.14	0.16	470
— Fe	3.86	0.65	6.30	2.95	0.92	0.55	190
Control	3.07	0.56	8.50	1.75	0.34	0.18	742
			Corms				
— N	0.52	0.37	1.42	0.20	0.27	0.14	214
— P	1.35	0.05	1.84	0.28	0.28	0.26	113
— K	4.21	1.35	0.40	1.15	0.57	0.44	400
— Ca	3.42	0.81	2.45	0.20	0.76	0.33	214
— Mg	2.50	0.65	2.70	0.56	0.20	0.25	214
— S	1.94	0.63	1.46	0.47	0.40	0.10	152
— Fe	1.94	0.43	2.00	0.62	0.47	0.18	155
Control	2.21	0.42	1.77	0.42	0.34	0.14	175

* Plant showing severe magnesium deficiency symptoms grown on Brasso Clay, Central Trinidad.

Deficiency Symptoms

(i) *Leaf*

Growth in complete nutrient solution

In the complete nutrient solution growth was vigorous and large leaves were produced. The laminae were a moderately dark green colour.

Growth in nutrient deficient solutions

Nitrogen: Growth was severely restricted and leaves with very small laminae and short petioles were produced. The leaves were pale green in colour.

Sulphur: Growth was somewhat restricted and leaves with relatively small laminae and short petioles were produced though the effect was not as severe as with nitrogen shortage. The leaves were uniformly pale green to pale yellow in colour.

Phosphorus: Growth was also affected by lack of phosphorus, small leaves with short petioles being produced. The colour of the leaves was unaffected. However, the leaves had a more shiny appearance lacking the bloom of control plants.

Calcium: Shortage of calcium produced restricted growth,smaller laminae and shorter petioles than in control plants. The laminae appeared thicker than in control plants and were somewhat leathery to the touch. As symptoms progressed the youngest leaf became distored with irregular chlorotic and necrotic patches. Leaves senesced rapidly at this stage, very small distorted leaves were produced and the plants finally died.

Potassium: Somewhat smaller leaves with shorter petioles were produced in comparison with control plants but the effect was not as great as with lack of nitrogen, sulphur or phosphorus. However, a distinct symptom appeared in the older leaves. Narrow water-soaked areas appeared at three or four points at the margin of the laminae, these areas rapidly drying to give thin papery grey to brown patches. Further, such areas developed on the margin until a narrow band of necrotic tissue existed from the tip to the shoulders of the laminae, the band penetrating for a short distance towards the centre of the leaf between the main veins. A narrow yellowish band occurred adjacent to the inner edge of the necrotic band.

Observations in early morning suggested an association between the appearance of the water-soaked areas and guttation. Guttation drops occured at the water-soaked points and in some instances a bladder had formed which later in the day dried out to give the characteristic dry papery patch.

Magnesium: Magnesium deficiency produced striking leaf symptoms, a bright orange colour appearing between the main veins, starting first towards the half of the lamina towards the tip and spreading over the whole surface of the lamina. Dark green bands remained along the main veins and first order secondary veins and also for some time along the marginal vein. The interveinal areas towards the tip then dried out and the leaves rapidly senesced. The sequence of symptoms on successive leaves was very regular, the orange colour appearing on the second open leaf just as the third leaf senesced. Thus usually only one leaf at a time showed these symptoms which progressed rapidly until the leaf senesced. The size of leaves was not affected but fewer leaves occurred than on control plants.

Very similar symptoms were observed on plants growing in a citrus field and as mentioned earlier, tissue analysis (Table 1) of such plants showed very low levels of magnesium.

Iron: Relatively mild symptoms or iron deficiency were obtained. Growth was not affected and an interveinal pattern of a lighter green colour appeared.

Narrow dark green bands remained on the main and first and second order secondary veins. It is intended to undertake further trials in an attempt to produce more severe iron deficiency symptoms.

(ii) *Roots and corms*

In the treatments lacking nitrogen, sulphur and phosphorus, a smaller root system was produced than in control plants and a fair size corm in relation to growth of the whole plant. The comparatively larger size corm in relation to leaves was most marked in the minus nitrogen treatment and was similar to effects of the same treatment given to sweet potato plants (Spence and Ahmad 1967) where a very restricted leaf area allowed development of a fair-sized tuber.

In the minus calcium treatment there was severe dying back of roots so that as marked leaf symptoms appeared there was little root system left and death of the whole plant occurred rapidly. The size of corm in relation to leaves was similar to the control plants.

Lack of potassium resulted in a small root system and magnesium deficiency was associated with dying back of roots. The minus iron treatment produced a root system similar to the controls.

SUMMARY AND CONCLUSIONS

Characteristic and severe symptoms of deficiency were produced by lack of the major plant nutrients nitrogen, sulphur, phosphorus, potassium, magnesium and calcium and mild symptoms with lack of iron.

Tissue analysis indicated low contents of the plant nutrients in relation to treatment. This analysis further indicated a high level of potassium in leaves and petioles and in roots, except where this nutrient was omitted.

The association of onset of potassium deficiency symptoms with guttation deserves further investigation.

A related edible aroid, *Colocasia antiquorum*, is reported to secrete up to 400 ml per day of almost pure water (Bennet-Clark, 1959). If, as appears to be the case for tannia, potassium deficiency upsets this system of secretion then further investigation may throw light on the symptom development and/or the mechanism of secretion.

Also of interest were the characteristic magnesium deficiency symptoms and the occurrence of such symptoms in the field in association with low magnesium content in leaf tissue of both tannia and citrus. This suggests the possibility for use of tannia as an indicator plant for magnesium deficiency.

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By J. A. SPENCE AND N. AHMAD

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THE RESPONSE OF TARO (COLOCASIA ESCULENTA [L.] SCHOTT) TO N, P, AND K FERTILIZATION UNDER UPLAND AND LOWLAND CONDITIONS IN HAWAII

— *by* —

Ramon S. de la Pena and Donald L. Plucknett

Taro is one of man's oldest food crops. Records of taro cultivation date back to 400 B.C. It is widely used throughout the tropic, sub-tropic and sub-temperate zones as a vegetable or a starch source. It is used for food either as boiled, diced cubes or as "poi", a paste made from boiled, mashed corms allowed to ferment a day or more. It is also sliced and baked or made into taro chips. Dieticians have long recognized the unique properties of poi as a baby food (Derstine and Rada, 1952; Miller, 1927, 1929; Miller, Bauer and Denning, 1952). Clinical studies conducted to determine the food properties of poi confirmed it values as food for normal, allergic, and potentially allergic babies (Glaser, Lawrence, Harrison and Ball, 1965).

Taro is of primary importance in the Pacific Basin because it is the staple food of most of the inhabitants. In most of Asia and Africa, it is used as a vegetable similar to potato or sweet potato. In the Hawaiian Islands it is still an economically important crop despite the rapidly declining acreage devoted to its production.

Despite its importance, little is known of the fertility and nutrient requirements of the taro plant. This research was designed to study the response of taro to relatively high rates of fertilization and to investigate the N,P, and K requirements of taro under upland and lowland conditions in Hawaii.

MATERIAL AND METHODS

Two field experiments were established in the island of Kauai. A pot experiment was conducted in the Manoa campus of the University of Hawaii The lowland paddies were located in Hanalei Valley, the major taro producing area of the state. The site is about 3m above sea level with an average annual rainfall of 230 cm. The soil is classified as a Hanalei Paddy.

The upland plots were located at the Kauai Branch Experiment Station of the University of Hawaii. The site is about 150 m above sea level with an average annual rainfall of 240 cm The soil is classified in the Halii series of the Aluminous Ferruginous Latosol Great Soil Group.

The field experiments were laid out in an incomplete factorial design with 12 treatments and three replications. One-third of the N and K and all of the P fertilizers were applied before planting. The remaining N and K were applied in equal amounts two and four months after planting. The plots were 4.5 x 6 m and the plants were spaced 45 x 60 cm.

Twenty-four 5-gallon cans were filled with about 15 Kg of air-dried Waimanalo soil (Low Humic Latosol) and a completely randomized 2 x 2 x 2 N-P-K interaction experiment was set-up with three replications. Rates of fertilizers used were uniform for N, P, and K being 0 and 15 g per pot Just before planting, one-third of the N and K and all of the P fertilizers were thoroughly mixed with the soil and the remaining N and K were applied in equal amounts at two and four months after planting. In all experiments, urea, treble super phosphate and potassium sulfate were used as sources of the elements.

Periodic plant samples were collected consisting of the petioles and blades of the physiologically most active leaves of three plants per plot. Petioles and blades were analyzed separately for N, P, K, Ca and Mg. Nitrogen was analyzed by the Kjeldahl method modified to include nitrates (A.O.A.C. 1960), P. colorimetrically as the ammonium-vanadate yellow complex. Potassium was analyzed using a Beckman Model Du flamephotometer. Calcium and Mg were complexometrically analyzed by titration with EDTA using Calcon and Eriochrome Black T indicators (Black, 1965).

Harvesting consisted of pulling 15 plants per plot at 12, 14 and 15 months from the fields. The main and sucker corms were weighed separately. In the pot experiment, the plants were pulled out at the age of six months. The roots, corms and leaves were thoroughly washed and prepared separately for chemical analysis.

RESULTS AND DISCUSSION

Nitrogen fertilization

The total yields in tons per hectare of upland lowland taro as affected by increasing rates of N applications are shown in tables 2 and 3. Statistical analysis of the yield data shows significant differences among means of different treatments both in the upland and lowland fields. In the upland crop, however, only increasing N fertilization increased the yields significantly whereas in the lowland, both fertilization and date of harvesting gave significant increases in the yields which seems to indicate that upland taro matures earlier than lowland taro.

The highest yield in upland taro fertilized with N were obtained from plots which received 560 Kg/Ha N. The yields at 280 and 1120 Kg/Ha N were also higher than those of the control; the decrease in yields at the highest level of N was probably due to inadequate supply of other nutrients or the imbalance brought about by the excessive supply of N.

In the lowland taro, the highest yields were obtained from the plots given 1120 Kg/Ha N. Although the trend in yield increase for both crops was curvilinear, the highest rate of N application did not seem to upset the balance of nutrients in the lowland field since analysis of both soils showed that the lowland fields had higher fertility level than the upland field (Table 1).

The composition of leaves of both upland and lowland taro was affected significantly by fertilization and age (Tables 4 and 5). In upland taro, only per cent N in the petioles was increased significantly by N fertilization. Per cent P, K and Ca decreased with application of N, while Mg tended to increase but the increase was not significant. In the blades, per cent N and Mg increased significantly when N fertilization increased. Per cent P, K and Ca in the blades decreased significantly with N fertilization and age.

Per cent N and Mg in the leaves of lowland taro showed significant increases due to N fertilization and decreases due to maturation. The effect of N applications and age on per cent P and K of lowland taro leaves is similar to those obtained from the upland crop.

Table 1.—Analysis of soils used in the field experiments.[1]

	Lowland	Upland
pH	5.67	4.58
C. E. C. me./100 g. O.D.	17.45	24.49
Exch. Ca me./100 g. O.D.	9.77	1.54
Exch. Mg me./100 g. O.D.	3.92	0.45
Exch. K me./100 g. O.D.	0.323	0.260
Total N %	0.22	0.23
Ext. P ppm	319.4	9.4
Sand fraction %	54	5

1 Average of determinations from 36 plots.

Table 2.—Effects of nitrogen on total yields (tons/hectare) of upland taro.[1]

Treatment Kg. N/Ha.	Age at harvest 12 months	14 months	15 months
0 (Control)	6.69	6.18	7.32
0	9.67^{c}	12.63^{bc}	9.77^{c}
180	18.58^{ab}	21.27^{ab}	20.63^{ab}
560	22.56^{a}	22.40^{a}	25.54^{a}
1120	19.56^{ab}	17.23^{abc}	16.67^{abc}

1 Differences among values with the same letter in the superscript are not significant. Control data not included in statistical analysis.

Table 3.—Effects of nitrogen on the yields (tons/hectare) of upland taro.[1]

Treatment Kg. N/Ha.	Age at harvest 12 months	14 months	15 months
0 (Control)	24.06	28.97	32.49
0	24.73^{f}	36.85^{de}	33.14^{e}
280	32.81^{e}	41.29^{cd}	44.02^{c}
560	33.45^{e}	51.54^{ab}	50.41^{b}
1120	37.95^{cde}	55.01^{ab}	57.62^{a}

1 Differences among values with the same letter in the superscript are not significant. Control data not included in statistical analysis.

Table 4.—Effects of nitrogen fertilization composition of upland taro leaves.[1]

Treatments Kg./Ha. N	Petioles Age in months 3	6	9	12	Blades Age in months 3	6	9	12
				Per cent N				
0 (Control)[2]	1.25	1.12	0.80	1.29	3.75	3.27	3.09	3.43
0	1.00	1.04	0.77	1.11	3.64	3.30	3.02	3.32
280	1.63	1.20	0.73	1.11	4.09	3.80	3.33	3.20
560	2.28	1.72	0.82	1.18	4.45	4.14	3.69	3.46
1120	2.70	1.82	0.87	1.32	4.88	4.33	3.64	3.51
				Per cent P				
0 (Control)	0.132	0.164	0.164	0.203	0.231	0.265	0.251	0.270
0	0.312	0.411	0.431	0.385	0.356	0.338	0.313	0.337
280	0.165	0.158	0.275	0.281	0.340	0.281	0.288	0.298
560	0.164	0.144	0.178	0.285	0.317	0.281	0.288	0.314
1120	0.162	0.144	0.185	0.232	0.316	0.288	0.298	0.293
				Per cent K				
0 (Control)	8.40	7.30	3.32	4.76	4.73	5.27	3.91	4.03
0	10.70	7.99	6.33	6.85	5.52	5.30	4.90	4.40
280	10.13	7.85	5.77	5.33	5.70	5.79	4.77	4.05
560	9.15	7.10	4.19	4.50	5.07	5.46	3.92	3.72
1120	7.90	6.27	3.65	4.80	4.63	5.00	4.12	3.98
				Per cent Ca				
0 (Control)	1.19	0.87	0.72	1.08	1.39	1.24	1.16	1.63
0	1.06	0.71	0.57	0.88	1.29	1.03	1.21	1.44
280	0.87	0.66	0.57	0.76	1.17	0.92	0.92	1.25
560	0.95	0.83	0.57	0.81	1.20	0.95	0.89	1.32
1120	0.97	0.75	0.54	0.74	1.19	0.75	0.75	1.10
				Per cent Mg				
0 (Control)	0.10	0.15	0.13	0.14	0.18	0.13	0.22	0.24
0	0.10	0.12	0.10	0.12	0.15	0.11	0.19	0.21
280	0.11	0.13	0.12	0.14	0.18	0.15	0.19	0.23
560	0.12	0.18	0.12	0.15	0.19	0.17	0.20	0.23
1120	0.13	0.14	0.11	0.12	0.20	0.15	0.17	0.22

[1] Average of three replications. Results of analysis expressed in per cent oven dry basis.

[2] Control plots were not fertilized, all other treatments received basic applications of 280 Kg./Ha. each of P and K.

Table 5.—Effects of nitrogen fertilization on composition of lowland taro leaves.[1]

Treatments Kg./Ha. N	Petioles				Blades			
	Age in months							
	3	6	9	12	3	6	9	12
	Per cent N							
0 (Control)[2]	1.00	0.97	0.81	0.65	4.02	4.09	3.13	2.78
0	0.99	0.98	0.73	0.63	4.11	4.10	3.18	2.77
280	1.06	1.05	0.71	0.64	4.32	4.23	3.23	2.99
560	1.22	1.39	0.76	0.68	4.37	4.61	3.47	3.09
1120	1.38	1.81	0.87	0.61	4.77	4.96	3.69	2.98
	Per cent P							
0 (Control	0.268	0.570	0.516	0.312	0.400	0.477	0.377	0.319
0	0.353	0.654	0.517	0.355	0.437	0.499	0.359	0.320
280	0.381	0.645	0.476	0.337	0.461	0.522	0.380	0.321
560	0.364	0.629	0.438	0.251	0.457	0.568	0.376	0.322
1120	0.247	0.581	0.339	0.237	0.435	0.565	0.343	0.307
	Per cent K							
0 (Control)	2.05	3.60	1.93	1.02	2.83	4.30	2.85	2.60
0	4.61	6.40	3.94	1.76	4.44	5.23	4.27	3.45
280	4.03	5.69	3.49	1.64	4.06	4.97	4.14	3.37
560	3.05	4.77	2.33	0.97	3.37	4.80	3.34	2.71
1120	2.30	3.90	1.44	0.85	2.99	4.53	2.70	2.46
	Per cent Ca							
0 (Control)	0.77	0.74	0.88	0.69	1.59	1.55	1.55	1.76
0	0.64	0.62	0.72	0.70	1.22	1.22	1.25	1.66
280	0.67	0.71	0.71	0.51	1.11	1.29	1.28	1.43
560	0.74	0.80	0.77	0.45	1.31	1.29	1.32	1.01
1120	0.85	0.74	0.64	0.42	1.43	1.22	1.27	1.02
	Per cent Mg							
0 (Control)	0.58	0.44	0.48	0.33	0.71	0.35	0.35	0.33
0	0.46	0.33	0.31	0.32	0.62	0.32	0.24	0.27
280	0.52	0.41	0.34	0.32	0.51	0.35	0.24	0.27
560	0.61	0.49	0.45	0.29	0.64	0.35	0.33	0.27
1120	0.56	0.49	0.45	0.32	0.62	0.33	0.38	0.29

1 Average of three replications. Results of analysis expressed in per cent oven dry basis.

2 Control plots were not fertilized, all other treatments received basic applications of 280 Kg/Ha. each of P and K.

Phosphorus Fertilization

Corm yields of both upland and lowland taro in tons per hectare are shown in Tables 6 and 7. Yields of both crops increased significantly as P fertilizer increased. In the upland, the effect of P is curvilinear and the highest yields were obtained from plots fertilized with 560 Kg/Ha P. Delayed harvesting did not give significant effect on yields of upland taro, again showing that upland taro matures earlier than lowland taro.

Yields of lowland taro were significantly influenced by increasing rates of P fertilization and delayed harvesting. The highest yields were obtained from plots which received 1120 Kg/Ha P and which were harvested at the age of 15 months.

Leaf composition of upland and lowland taro fertilized with increasing rates of P are shown in Tables 8 and 9. The per cent P in petioles of upland taro was directly related to P fertilization while other elements studied were negatively affected by P applications. In the blades, only P content was significantly affected by P fertilization. With the exception of Mg, tissue content of other elements decreased with the age of the plants.

Similarly, the composition of the lowland taro leaves was influenced by P fertilizer and age. The decrease in per cent K was the only significant change, although P, Ca and Mg tended to decrease. All elements studied decreased significantly as plants reached maturity. In the blades, N, P, K, Ca and Mg were significantly affected by age of the plants when the samples were collected.

Potassium fertilization

Significant increase in yields of upland taro due to increased fertilization with K were obtained (table 10). Delayed harvesting gave a slight decrease in yields, but the effect was not statistically significant. In the lowland, there were no significant increases in corm yield due to fertilization with K. Yield increase due to delayed harvesting, however, were highly significant (table 11). Highest mean yield obtained from upland fields were from plots fertilized with 1120 Kg/Ha K and harvested at the age of 12 months. In the lowland, highest yields were obtained from plots which received 1120 Kg/Ha K, but harvested at the age of 15 months. Yields obtained at 15 months from lowland paddies which received 1120 Kg/Ha K were not significantly higher than yields from 0, 280 and 560 Kg/Ha K plots, but were significantly higher than yields obtained at 12 months.

Per cent N, P and K in petioles of upland taro increased with K fertilization (table 12). The increases in per cent N and K were highly significant while the increase in per cent P was not significant. Potassium application significantly decreased Ca and Mg content of the petioles. Age also affected the composition of the petioles; per cent N, K and Ca decreased significantly as the plants matured. Per cent P increased significantly, while increase in per cent Mg was not significant. The composition of leaf blades of upland taro showed the same trends as those found in the petioles, however, increase in per cent N and P were not significant while increase in per cent K and decreases in per cent Ca and Mg were highly significant. The only element analyzed in the blade which increased as the plants matured was Mg, all other constituents decreased significantly (1 % level of significance).

Table 6.—Effects of phosphorus on the yields (tons/hectare) of upland taro.[1]

Treatment Kg. P/Ha.	Age at harvest 12 months	14 months	15 months
0 (Control)	6.69	6.18	7.32
0	14.01^{g}	16.80^{fg}	14.91^{fg}
280	18.58^{efg}	21.27^{cdefg}	20.63^{defg}
560	29.66^{bcd}	26.94^{bcde}	40.18^{a}
1120	32.10^{a}	23.84^{bcdef}	30.09^{bc}

1 Defferences among values with the same letter in the superscript are not significant. Control data not included in statistical analysis.

Table 7.—Effects of phosphorus on the yields (tons/hectare) of lowland taro.[1]

Treatment Kg. P/Ha.	Age at harvest 12 months	14 months	15 months
0 (Control)	24.06	28.97	32.49
0	29.26^{ef}	38.67^{bcd}	39.27^{bcd}
280	32.81^{cdef}	41.29^{abc}	44.02^{ab}
560	24.47^{f}	37.69^{bcde}	38.18^{bcde}
1120	31.42^{def}	46.80^{ab}	48.66^{a}

1 Differences among values with the same letter in the superscript are not significant. Control data not included in statistical analysis.

Table 8.—Effects of phosphorus fertilization on composition of upland taro leaves.[1]

Treatments Kg./Ha. P	Petioles				Blades			
	Age in months							
	3	6	9	12	3	6	9	12
				Per cent N				
0 (Control)[2]	1.25	1.12	0.80	1.29	3.75	3.27	3.09	3.43
0	2.48	1.70	0.84	1.25	4.38	3.99	3.53	3.53
280	1.63	1.20	0.73	1.11	4.09	3.80	3.33	3.20
560	2.12	1.48	0.83	1.32	4.23	3.99	3.68	3.74
1120	2.00	1.21	0.77	1.22	4.28	3.72	3.16	3.66
				Per cent P				
0 (Control)	0.112	0.164	0.164	0.203	0.231	0.265	0.251	0.270
0	0.118	0.128	0.120	0.159	0.232	0.254	0.245	0.266
280	0.165	0.158	0.275	0.281	0.340	0.281	0.288	0.298
560	0.239	0.143	0.228	0.313	0.340	0.287	0.310	0.320
1120	0.311	0.154	0.244	0.461	0.407	0.283	0.319	0.379
				Per cent K				
0 (Control)	8.40	7.30	3.32	4.76	4.73	5.27	3.91	4.03
0	10.90	8.68	5.67	6.20	5.39	5.38	4.65	4.15
280	10.13	7.85	5.77	5.33	5.70	5.79	4.77	4.05
560	9.67	7.26	5.12	5.51	5.70	5.23	4.59	3.93
1120	8.77	7.08	4.60	5.27	5.50	5.13	4.50	4.11
				Per cent Ca				
0 (Control)	1.19	0.87	0.72	1.08	1.39	1.24	1.16	1.63
0	0.99	0.77	0.68	0.81	1.13	0.89	1.04	1.27
280	0.87	0.66	0.57	0.76	1.17	0.92	0.92	1.25
560	0.87	0.71	0.56	0.78	1.16	0.95	0.95	1.23
1120	0.94	0.82	0.53	0.90	1.27	0.96	1.11	1.35
				Per cent Mg				
0 (Control)	0.10	0.15	0.13	0.14	0.18	0.13	0.22	0.24
0	0.09	0.13	0.10	0.16	0.16	0.14	0.20	0.26
280	0.11	0.13	0.12	0.14	0.18	0.15	0.19	0.23
560	0.13	0.12	0.13	0.15	0.18	0.14	0.20	0.25
1120	0.13	0.12	0.10	0.12	0.19	0.14	0.17	0.20

[1] Average of three replications. Results of analysis expressed in per cent oven dry weight.

[2] Control plots were not fertilized. All other treatments received basic applications of 280 Kg./Ha. each of N and K.

Table 9.—Effects of phosphorus fertilization on composition of lowland taro leaves.[1]

Treatments Kg./Ha. P	Petioles				Blades			
	Age in months							
	3	6	9	12	3	6	9	12
				Per cent N				
0 (Control)[2]	1.00	0.97	0.81	0.65	4.02	4.09	3.13	2.78
0	1.31	1.17	0.74	0.62	4.74	4.44	3.30	3.07
280	1.06	1.05	0.71	0.64	4.32	4.23	3.23	2.90
560	1.16	1.19	0.73	0.66	4.61	4.46	3.50	2.99
1120	1.10	1.27	0.74	0.70	4.28	4.42	3.43	3.06
				Per cent P				
0 (Control)	0.268	0.570	0.516	0.322	0.400	0.477	0.377	0.319
0	0.326	0.670	0.419	0.291	0.492	0.532	0.359	0.344
280	0.381	0.645	0.476	0.337	0.461	0.522	0.380	0.321
560	0.374	0.670	0.468	0.299	0.485	0.560	0.394	0.334
1120	0.372	0.639	0.431	0.288	0.465	0.568	0.374	0.335
				Per cent K				
0 (Control)	2.05	3.60	1.93	1.02	2.83	4.30	2.85	2.60
0	5.02	6.00	2.33	1.33	4.45	4.70	3.32	3.08
280	4.03	5.69	3.49	1.64	4.06	4.97	4.14	3.37
560	3.85	5.63	2.52	1.26	4.10	4.83	3.45	2.76
1120	3.75	5.00	1.93	1.00	3.94	4.83	3.12	2.55
				Per cent Ca				
0 (Control)	0.77	0.74	0.88	0.69	1.59	1.55	1.55	1.76
0	0.61	0.69	0.74	0.56	1.09	1.24	1.21	1.42
280	0.67	0.71	0.71	0.51	1.11	1.29	1.28	1.43
560	0.66	0.79	0.71	0.49	1.10	1.37	1.23	1.37
1120	0.66	0.67	0.71	0.53	1.13	1.27	1.32	1.28
				Per cent Mg				
0 (Control)	0.58	0.44	0.48	0.33	0.71	0.35	0.35	0.33
0	0.60	0.44	0.37	0.31	0.64	0.37	0.30	0.29
280	0.52	0.41	0.34	0.32	0.51	0.35	0.24	0.32
560	0.45	0.45	0.39	0.31	0.52	0.35	0.28	0.35
1120	0.53	0.46	0.39	0.31	0.55	0.35	0.31	0.33

[1] Average of three replications. Results of analysis expressed in per cent oven dry weight.

[2] Control plots were not fertilized. All other treatments received basic applications of 280 Kg./Ha. each of N and K.

Table 10.—Effects of potassium on the yields (tons/hectare) of upland taro.[1]

Treatment	Age at harvest		
Kg. K/Ha.	12 months	14 months	15 months
0 (Control)	6.69	6.18	7.32
0	16.90[bc]	18.08[abc]	14.85[c]
280	18.58[abc]	21.27[abc]	20.63[abc]
560	26.77[ab]	25.52[ab]	20.95[abc]
1120	27.77[a]	20.75[abc]	23.09[abc]

1 Differences among values with the same letter in the superscript are not significant. Control data not included in statistical analysis.

Table 11.—Effects of potassium on the yields (tons/Ha.) of lowland taro.[1]

Treatment	Age at harvest		
Kg. K/Ha.	12 months	14 months	15 months
0 (Control)	24.06	28.97	32.49
0	31.97[b]	41.81[a]	45.32[a]
280	32.81[b]	41.29[a]	44.02[a]
560	29.94[b]	42.47[a]	43.75[a]
1120	32.27[b]	41.32[a]	45.99[a]

1 Differences among values with the same letter in the superscript are not significant. Control data not included in statistical analysis.

Table 12—Effects of potassium fertilization on composition of upland taro leaves.[1]

Treatments Kg./Ha. K	Petioles				Blades			
	Age in months							
	3	6	9	12	3	6	9	12
	Per cent N							
0 (Control)[2]	1.25	1.12	0.80	1.29	3.75	3.27	3.09	3.43
0	1.62	1.19	0.73	1.33	4.20	3.86	3.16	3.47
280	1.63	1.20	0.73	1.11	4.09	3.80	3.33	3.20
560	1.69	1.83	0.92	1.21	4.18	3.87	3.50	3.23
1120	1.92	2.27	0.88	1.30	4.12	3.95	3.59	3.68
	Per cent P							
0 (Control)	0.112	0.164	0.164	0.203	0.231	0.265	0.251	0.270
0	0.147	0.143	0.253	0.311	0.293	0.296	0.306	0.321
280	0.165	0.158	0.275	0.281	0.340	0.281	0.288	0.298
560	0.201	0.145	0.270	0.350	0.339	0.362	0.299	0.305
1120	0.168	0.153	0.234	0.364	0.331	0.266	0.297	0.325
	Per cent K							
0 (Control)	8.40	7.30	3.32	4.76	4.73	5.27	3.91	4.03
0	3.10	2.71	3.13	3.53	3.20	3.30	3.31	3.24
280	10.13	7.85	5.77	5.33	5.70	5.79	4.77	4.05
560	10.27	9.61	5.70	5.86	6.10	6.28	4.67	4.20
1120	11.15	11.27	5.90	7.11	6.17	6.35	4.69	4.53
	Per cent Ca							
0 (Control)	1.19	0.87	0.72	1.08	1.39	1.24	1.16	1.63
0	1.17	1.04	0.63	0.95	1.87	1.78	1.30	1.44
280	0.87	0.66	0.57	0.76	1.17	1.92	0.92	1.25
560	0.84	0.68	0.60	0.84	1.16	0.88	0.77	1.27
1120	0.87	0.63	0.55	0.67	1.22	0.92	0.65	0.97
	Per cent Mg							
0 (Control)	0.10	0.15	0.13	0.14	0.18	0.13	0.22	0.24
0	0.19	0.26	0.18	0.22	0.31	0.27	0.24	0.33
280	0.11	0.13	0.12	0.14	0.18	0.15	0.19	0.23
560	0.11	0.13	0.13	0.12	0.16	0.14	0.22	0.21
1120	0.10	0.12	0.10	0.09	0.15	0.11	0.19	0.20

[1] Average of three replications. Results of analysis expressed in per cent oven dry weight.

[2] Control plots were not fertilized, all other treatments received basic applications of 280 Kg./Ha. each of N and P.

Increasing rates of K fertilization increased K in petioles of lowland taro significantly (table 13). Calcium and Mg in the petioles decreased significantly while P and N were not affected significantly. Phosphorus, K and Ca increased significantly as the plants matured whereas N and Mg decreased with age. In the blades, only the K content increased significantly with increasing K fertilizers. Potassium fertilization had negative effects on N, P, Ca, and Mg contents of the blades. Decreases in per cent Ca and Mg were highly significant while decreases in per cent N and P were not. Phosphorus, K and Ca also increased significantly as the plants grew old while N and Mg decreased.

N-P-K interactions

Results of the pot experiment showed that only N gave significant increases in the weights of corms, roots and leaves of the plants. Nitrogen deficiency characterized by general yellowing of the plants was observed in all plants which did not receive N fertilization. No P and K deficiencies were observed even though plant analysis gave P and K contents of as low as 0.15% and 1.5%, respectively in the petioles of N-treated plants and about 0.2% P and 2.0% K in the blades.

Table 14 shows the weights of corms, roots and tops of the plants at six months. Phosphorus and K fertilization tended to increase the growth of the plants but the effects were not significant.

The concentrations of N, P and K in the individual leaves decreased from the youngest to the oldest, except P which increased from the youngest to the oldest when P supply in the soil was not limiting (table 15). Composition of the roots and crops is also influenced by fertilization (table 16).

The results of the tissue analysis are very encouraging since they are suggestive of the feasibility of using leaf analysis as a possible guide to the fertilizer needs of the taro crop.

Table 13.—Effects of potassium fertilization on composition of lowland taro leaves.[1]

Treatments Kg /Ha. P.	Petioles				Blades			
	Age in months							
	3	6	9	12	3	6	9	12
				Per cent N				
0 (Control)[2]	1.00	0.97	0.81	0.65	4.02	4.09	3.13	2.78
0	1.21	1.18	0.78	0.74	4.62	4.42	3.31	3.11
280	1.06	1.05	0.71	0.64	4.32	4.23	3.23	2.90
560	1.11	1.17	0.69	0.66	4.51	4.29	3.24	2.81
1120	1.12	1.22	0.71	0.71	4.30	4.22	3.25	2.85
				Per cent P				
0 (Control)	0.268	0.570	0.516	0.312	0.400	0.477	0.377	0.319
0	0.327	0.628	0.463	0.307	0.437	0.542	0.377	0.333
280	0.381	0.645	0.476	0.337	0.461	0.522	0.380	0.321
560	0.363	0.684	0.472	0.316	0.455	0.547	0.362	0.316
1120	0.361	0.678	0.405	0.316	0.439	0.530	0.342	0.306
				Per cent K				
0 (Control)	2.05	3.60	1.93	1.02	2.83	4.30	2.85	2.60
0	1.85	2.87	1.36	0.92	2.51	3.56	2.30	2.28
280	4.03	5.69	3.49	1.64	4.06	4.97	4.14	3.37
560	5.50	6.93	3.24	1.49	4.83	5.27	3.90	3.32
1120	7.23	8.51	4.15	2.24	5.42	5.87	4.30	3.62
				Per cent Ca				
0 (Control)	0.77	0.74	0.88	0.69	1.59	1.55	1.55	1.76
0	0.81	0.84	0.77	0.58	1.47	1.65	1.44	1.33
280	0.67	0.71	0.71	0.51	1.11	1.29	1.28	1.43
560	0.56	0.71	0.60	0.58	0.91	1.19	1.14	1.39
1120	0.50	0.62	0.45	0.52	0.86	1.13	1.02	1.09
				Per cent Mg				
0 (Control)	0.58	0.44	0.48	0.33	0.71	0.35	0.35	0.33
0	0.57	0.58	0.46	0.33	0.68	0.43	0.45	0.37
280	0.52	0.41	0.34	0.32	0.51	9.35	0.24	0.32
560	0.42	0.40	0.33	0.33	0.52	0.36	0.25	0.27
1120	0.40	0.38	0.25	0.27	0.56	0.40	0.26	0.28

[1] Average of three replications. Results of analysis expressed in per cent oven dry weight.

[2] Control plots were not fertilized, all other treatments received basic application of 280 Kg./Ha. each of N and P.

Table 14.—Weight of corms, roots and tops of taro plants grown in pots.[1]

Treatments	Corms Fresh wt.	Roots Dry wt.	Tops[2] Dry wt.
		grams per plant	
Control	49.60	1.04	8.76
N	478.36	22.27	86.67
P	73.12	1.93	10.86
K	76.90	1.72	8.50
NP	654.49	22.49	67.44
NK	661.88	41.85	69.93
PK	70.72	2.38	11.54
NPK	771.67	26.39	64.32

[1] Average of three replications.

[2] Tops include petioles and blades.

Table 15.—*Composition of the petioles and blades of individual leaves of six-month old taro grown in pots.*[a]

Treatments	Petioles Leaf number 1	2	3	4	Blades Leaf number 1	2	3	4
				Per cent nitrogen				
Control	0.88	0.84	0.84	0.79	3.16	3.29	3.00	2.53
N	1.02	0.86	0.81	0.77	3.67	3.60	3.27	2.83
P	0.95	0.93	0.89	0.85	3.51	3.63	3.19	2.85
K	1.16	0.93	0.89	0.82	3.84	3.52	3.49	3.01
NP	1.41	1.06	0.83	0.79	4.06	3.49	3.33	2.86
NK	1.10	0.95	0.87	0.85	3.77	3.65	3.36	2.69
PK	0.94	0.82	0.77	0.75	3.68	3.47	3.03	2.53
NPK	1.41	1.12	1.06	0.97	4.79	4.16	3.41	2.60
				Per cent phosphorus				
Control	0.562	0.714	0.822	1.126	0.424	0.372	0.344	0.382
N	0.232	0.168	0.154	0.140	0.326	0.260	0.214	0.204
P	0.628	0.828	0.932	1.210	0.478	0.526	0.498	0.508
K	0.646	0.624	0.702	0.836	0.512	0.386	0.376	0.366
NP	0.618	0.484	0.436	0.452	0.484	0.326	0.302	0.274
NK	0.274	0.200	0.163	0.154	0.352	0.260	0.228	0.200
PK	0.728	0.736	0.874	1.214	0.522	0.520	0.494	0.550
NPK	0.642	0.586	0.558	0.544	0.558	0.386	0.330	0.246
				Per cent potassium				
Control	4.20	4.55	4.40	4.95	4.05	3.64	3.00	3.00
N	2.52	1.84	1.46	1.16	3.24	2.60	2.15	1.68
P	4.20	4.05	3.80	3.90	3.80	3.64	3.08	2.75
K	5.68	4.90	4.90	4.74	4.80	4.45	3.56	3.56
NP	3.34	1.90	1.60	1.16	3.34	2.06	1.90	1.45
NK	5.96	5.10	4.55	4.55	4.00	4.20	3.65	3.90
PK	5.60	4.45	4.45	4.95	4.54	4.20	3.65	3.20
NPK	6.50	5.48	5.86	5.30	4.45	3.84	3.40	3.26

a Composite samples from three plants per treatment.

Table 16.—Nitrogen, phosphorus and potassium contents of the roots and corms of six-month old taro grown in pots.

	Roots			Corms		
Treatments	% N	% P	% K	% N	% P	% K
Control	0.79	0.248	5.05	0.23	0.198	1.00
N	0.93	0.095	0.75	0.81	0.152	0.56
P	0.89	0.394	4.90	0.33	0.239	0.94
K	0.78	0.214	5.52	0.25	0.197	1.04
NP	1.07	0.290	0.48	0.71	0.232	0.52
NK	1.20	0.116	4.00	0.60	0.121	1.20
PK	0.89	0.396	5.88	0.38	0.239	1.02
NPK	1.20	0.276	3.40	0.60	0.212	1.17

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THE INFLUENCE OF FERTILIZER RATIOS ON SWEET POTATO YIELDS AND QUALITY

— *by* —

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The sweet potato occupies an important place in the Puerto Rican diet. It is of nutritional importance, not only for its high caloric value, but for its abundant vitamin content, especially vitamin A. The yellow fleshed variety U.P.R. No. 3, for instance, is exceptionally high in carotene, thus providing an inexpensive and abundant source of vitamin A for man and animal.

The cultivation of sweet potato ranks as one of the more important crops of Puerto Rico. They are grown in all areas of the Island. From 1963 to 1965, the average production per year of the sweet potato crop in the Island amounted to 13,600 tons at a mean cash value of $1,570,000 annually Annon 1966. The majority of the crop grown receives little or no fertilizer and a minimum of care. In general, the sweet potato crops are grown on poor or marginal land with little attention to proper agronomic practices. Most fertilizer studies have been devoted to rates of fertilizer applied. The purpose of this work is to evaluate the major nutrient requirements (N-P-K) of the sweet potato in regard to ratio and balance of elements rather than absolute quantities of materials used. The effect of these ratios is developed for yields and quality of sweet potatoes as reflected in the starch and carotene content.

EXPERIMENTAL PROCEDURE

The investigation consisted of three experiments covering a range of soil textures from loamy sand to heavy clay. The Loiza experiment was established on Catano loamy sand, a well-drained coastal lowland soil, alkaline in reaction (pH 7.6), devoted mostly to coconuts, citrus, sweet potato, cassava, beans, and peanuts. The Sabana Seca experiment was conducted on Sabana Seca sandy clay loam, a coastal plain soil, which has a friable surface soil (pH 6.3) and a heavy plastic subsoil, and is under cultivation mostly to minor truck crops. The Corozal experiment was established on Lares clay, a lateritic acid clay (pH 4.5) of the terrace and alluvial fans of Puerto Rico, cropped mainly to sugarcane and pineapples.

The fertilizer treatments for the three experiments utilized varying increments of nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O) to establish the various ratios given in Table I.

Table 1. Fertilizer ratios and quantity applied

Fertilizer ratio	Fertilizer applied pounds per acre N	P	K	P_2O_5	K_2O
N : K					
0 : 2	0	88	166	200	200
1 : 2	82	88	166	200	200
2 : 2	165	88	166	200	200
2 : 0	165	88	0	200	0
2 : 1	165	88	83	200	100
2 : 2	165	88	166	200	200
2 : 3	165	88	249	200	300
P : N					
0 : 2	165	0	166	0	200
0.5 : 2	165	44	166	100	200
1 : 2	165	88	166	200	200
1.5 : 2	165	132	166	300	200

The experimental design for all experiments was a triple lattice with six replications of each treatment. The plot size was 20 feet long by 8 feet wide or one two-hundred-and-seventy-second of an acre. The propagation material consisted of 40 vine cuttings (the first 18 inches of the sweet potato vine being used) per plot of U. P.R. No. 3, a Puerto Rican sweet potato variety. The vines were planted in four furrows, 2 feet apart and 3 to 4 inches deep.

The carotene content and starch analyses were conducted on random samples of 10 sweet potatoes per plot. In all cases, the same general shape and size were used which conformed with the U. S. No. 1 root. The material was prepared for analyses from 24 to 48 hours after harvesting. The carotene content was determined by the method of Moore and Ely (1941) and starch by the method of Nielson (1943).

RESULTS AND DISCUSSION

Yields

The same N : K ratio did not produce highest yields of sweet potatoes for each soil tested. Highest yields were associated with a 1 : 2 ratio for the Catano loamy sand and Sabana Seca sandy clay, whereas, the Lares clay gave highest yields with a 0 : 2 ratio (Table 2).

Table 2. The mean yields per acre of sweet potatoes as influenced by fertilizer ratios.

Fertilizer ratio	Catano loamy sand	Sabana Seca Sandy clay	Lares clay pH 6.0*	Lares clay pH 4.5
	Mean yield per acre in hundredweights			
N : K				
0 : 2	102	63	139	96
1 : 2	130	119	107	68
2 : 2	107	100	78	60
2 : 0	68	98	94	60
2 : 1	78	116	106	
2 : 2	107	100	78	
2 : 3	119	112	94	
P : N				
0 : 2	114	108	94	
0.5 : 2	116	112	88	
1 : 2	107	100	78	
1.5 : 2	89	113	119	
Least significant differences needed for comparison at :				
5-percent	27	15	24	24
1-percent	40	20	31	31

* Normal soil pH 4.5; soil raised to pH. 6 with 7,500 pounds $CaCO_3$ per acre.

The differences in the ratio responses may be in part due to the amount of soil nitrogen available to the plant apart from that supplied by the fertilizer. The Catano loamy sand and Sabana Seca sandy clay were low in available soil nitrogen and required some nitrogen fertilizer (100 pounds N per acre) for high yields of sweet potatoes. However, when more nitrogen was applied (200 pounds N per acre), the yields dropped off indicating that the excess nitrogen applied caused depressed root yields.

The relative supply of available nitrogen in the Lares clay must have been quite high as each nitrogen increment gave a yield decrease over the no-nitrogen level (Table 2). The field where the experiment was conducted was previously in pineapples. These had been heavily fertilized with high-nitrogen fertilizers at rates up to 400 pounds N per acre for several years. It is probable that the residual nitrogen was sufficient to give adequate nitrogen supplies for high root yields. The application of nitrogen fertilizer in this case only served to simulate vine growth and depress root yields. A white potato fertilizer experiment planted in this soil several years later failed to show any response to nitrogen fertilizer application Landrau *et al* (1955), Anderson (1936), Morgan (1939), and Sinno (1953) all report limited to no response to nitrogen application on fertile soils or those soils which have been in cover crops before planting sweet potatoes. The influence of increasing nitrogen in the presence of a constant potassium supply is best shown by the Lares clay and Sabana Seca experiments (Table 1 and Figure 1). Where some nitrogen is needed yields increase until the nitrogen level has been satisfied. After this increasing nitrogen causes yield decreases (Sabana Seca clay). Where soil nitrogen supplies are adequate, further nitrogen applications cause yield decreases (Lares clay experiment). At pH 6, the decrease for added nitrogen is linear. At pH 4.5 the decrease in yield is curvilinear with a decreasing change in slope as we change from and N : K ratio of 1 . 2 to 2 : 2 (Figure 1). This may be in part due to the fact that all of the added fertilizer nitrogen was not available to the plant. Recent work has shown that ammonium sulfate, the nitrogen source used in this experiment, when applied at high rates increases soil acidity Samuel and Gonzalez-Velez (1962) to levels where conversion of ammonia to nitrate nitrogen is hindered. Thus the full effect of the added nitrogen on decreasing yield could not be realized because of the inefficiency of nitrogen conversion at low soil pH.

High nitrogen applications stimulate vine growth as well as root production Johnson and Ware (1948) However, when nitrogen needs are satisfied, the additional nitrogen goes into vine production. Should potassium levels in the soil be in limited supply, high nitrogen application can induce potassium deficiencies and limit root yields at the expense of vine production. It was felt that increasing the potassium levels in the presence of high nitrogen could offset the harmfull effect of the nitrogen on root yields. The Catano loamy sand experiment showed quite well the ameliorating influence of potassium in the presence of high nitrogen. Yields increased progressively from 68 hundred weights per acre for the 2 : 0 N : K ratio to 119 with a 2 : 3 N : K ratio (Table 2). When the potash values exceeded the nitrogen values, yields returned to almost optimum for this experiment.

The beneficial influence of increasing potassium in the presence of high nitrogen did not prove as significant for the Sabana Seca sandy clay and was non-existent for the heavier textured Lares clay (Table 2).

Muller *et. al.* (1963) suggested that for sugar beets the importance of the N : K ratio in the fertilizer treatment must always be considered in close connection with the absolute level of the nitrogen fertilizer treatment as well as nitrogen available in the soil. At high nitrogen levels, the positive effect of a wide N : K ratio on yield is all the greater. At a low nitrogen level a much narrower N : K ratio will be effective. From this it follows than an absolute value cannot be given for the physiological optimum of the N : K ratio but that this is determined by the level of the nitrogen available to the plant.

It should be mentioned here that the amounts of fertilizer used in establishing the fertilizer ratios were quite high for a root crop such as sweet potatoes. Normally, fertilizer rates for sweet potato in Puerto Rico do not reach above 80 pounds per acre for N and P_2O_5, respectively, and 150 pounds for K_2O. Such high rates as 165 pounds of N per acre may have prevented full expression of the N : K relationship for sweet potatoes.

Increasing phosphorus levels in the presence of a constant supply of nitrogen and potassium did not appear to cause a marked influence on sweet potato yields for the three experiments in general. The Catano loamy sand sweet potato yields decreased as the P N ratio changed from 0 : 2 to 1.5 : 2 (Table 2). The Lares gave a slight but not significant decrease as P N ratio rose from 0 : 2 to 1 : 2 At a 1.5 : 2 ratio, the yields increased significantly.

It appears that the responses obtained with a varying phosphate supply was due to the amount of phosphate rather than the phosphorus : nitrogen ratio. Phosphate was not needed in the very light textured Catano sand with its neutral pH of 7.6. A rate of 300 pounds P_2O_5 per acre only served to depress root yields. On the other hand, the acid Lares clay limited to pH 6 needed high rates of phosphate before responses could be obtained. The lower rates – 100 and 200 pounds of P_2O_5 per acre – may have been unavailable to the plant and response was only found at the highest phosphate fertilizer application.

Stino (1953) working with sweet potatoes on a fertile clay loam in Egypt found that increasing phosphate in relation to potash from O : 2 to 1.5 : 2 P : N ratio gave a limited and variable response in root yield but ever increasing vine yield. Cibes and Samuels (1957) obtained large increases in vine growth at the expense of root production under phosphorus deficiencies in sweet potatoes.

Carotene and Starch

The carotene content of the sweet potato increased with narrowing N : K ration when potash remained constant for Catano loamy sand and Sabana Seca sandy clay (Table 3). There was no significant change in carotene content for the Lares clay. There was no trend for change in carotene when potassium was increased at constant nitrogen levels with the exception of a significantly large accumulation of carotene for the 2 : 0 N : K ratio on the Catano loamy sand experiment.

Table 3. The carotene and starch content of sweet potatoes as influenced by fertilizer ratios.

Fertilizer ratio N : K	Catano loamy sand Carotene Mg/g	Catano loamy sand starch Percent	Sabana Seca sandy clay Carotene Mg/g	Sabana Seca sandy clay Starch Percent	Lares clay pH 6.0* Carotene Mg/g	Lares clay pH 4.5 Carotene Mg/g
0 : 2	80	55	101	61	126	107
1 : 2	87	55	124	63	124	120
2 : 2	105	57	125	64	124	116
2 : 0	133	55	129	67	117	
2 : 1	95	50	124	66	121	
2 : 2	105	57	125	64	124	
2 : 3	102	50	125	66	129	
P : N						
0 : 2	95	51	117	62	113	
0.5 : 2	86	55	123	68	118	
1 : 2	105	57	125	64	124	
1.5 : 2	103	58	122	66	133	
Least significant differences needed for comparison at :						
5-percent	23	8	15	7	16	16
1-percent	31	10	20	9	22	22

* Normal soil pH 4.5; soil raised to pH 6 with 7,500 pounds $CaCO_3$ per acre.

Carotene tended to increase in the sweet potato as phosphorus levels rose. The increase in carotene was significant as the P : N ratio narrowed from a 0 : 2 to 1.5 : 2 ratio (Table 3).

It is interesting to note that the average carotene values for all the experiments was much higher than those citied by Coshran (1942) for the yellow fleshed "Puerto Rico" varieties in North Carolina.

The starch content showed no significant differences due to any of the N : K or P : N ratios used. Anderson (1936) and Morgan (1939) failed to find any influence of fertilizer level on the starch content of sweet potatoes.

SUMMARY

Field experiments in a Catano loamy sand, Sabana Seca sandy clay, and Lares clay were performed to evaluate varying ratios of nitrogen and potassium, and nitrogen and phosphorus on yields of sweet potatoes and their starch and carotene content. The results were as follows :

For the less fertile loamy sand and clay loam there was an increase in yields with a change from a N : K ratio of 0 : 2 to 1 : 2, however, yields decreased again when the N : K ratio reach 2 : 2. The more fertile clay soil gave decreased yields as the N : K ratio changed from 0 : 2 to 2 : 2. This indicated that for soils with lower available nitrogen supplies a 1 : 2 ratio gave optimum yields. For soils with high available nitrogen care must be used in keeping a wide N : K ratio.

Results with varying P : N ratios were mixed.

The influence of fertilizer ratios on starch content was insignificant. However carotene tended to increase with a narrowing N : K ratio for the loamy sand, and the sandy clay soils. Carotene content of the sweet potato increased with increasing phosphorus application.

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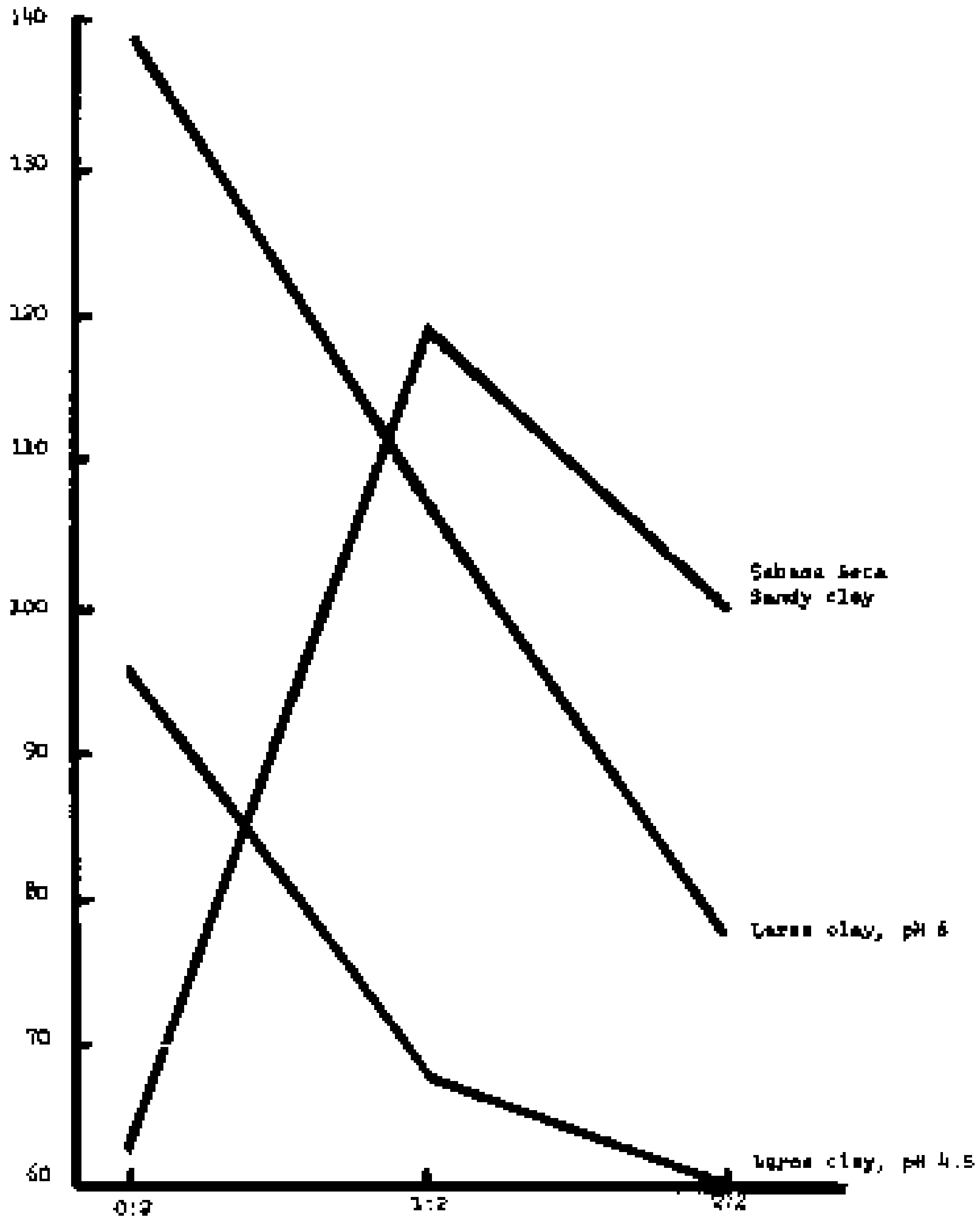

Fig. 1. - Influence of N:K ratio on Yields of sweet potatoes

DISCUSSION

Dr. Johnston :

I would first like to ask Mr. de la Pena whether the returns were economic to some of those extremely high levels of fertilisation which he reported ?

Mr. de la Pena :

We have not gone into the economics of this particular experiment since we were more interested in finding out what were the effects of fertilisation on the composition of the crop, and at present we are carrying on some experiments on the balance of these nutrients in the crop.

Mr. Sandys :

I would like to ask Dr. Samuels a practical question about cassava. I was in Africa for some years where cassava was always regarded as being a very exhaustive crop. On the other hand it was a crop which would grow in soils which would produce practically nothing else. I wonder whether, in fact, it has been shown that cassava is really a very exhaustive crop or whether the legend has grown up, because it is usually shown or seems to be growing in very exhausted soils.

Dr. Samuels :

I also have seen the literature abundant with the fact that cassava is an exhaustive crop, but if one makes analyses of the composition of the roots, and other parts of the plant, we find that it takes out quite a bit of nutrients, but not more so than many other crops. I think that it could not be considered as an exhaustive crop.

Dr. Spence :

I would like to ask Dr. Samuels about the characteristics of the sweet potato varieties. Were they high foliage varieties ? I note you got depression in yields with high nitrogen application. Was the variety used as a high foliage variety ?

Dr. Samuels :

I am going to pass this question to a colleague of mine, Mr. Moscoso, who is a sweet potato breeder. He might happen to know if this particular variety which we used which was the UPR 3 at that time, is considered a higher foliage variety in relation to the varieties growing here. Mr. Moscoso, UPR 3 or Cobre are they considered high foliage varieties ?

Mr. Moscoso :

These would be considered high foliage varieties in relation to the varieties you have here in Trinidad.

Dr. Sidrak :

I just want to make an observation on the tables which were presented by Mr. de la Pena. The graphs which he showed us reflect a very interesting feature.

For example, with the application of four different nitrogen levels to the soil, the leaf blades and petioles reflected these differences at three months, but failed to do so at nine months.

In the case of phosphorus, especially in the upland experiments, the leaf phosphorus was parallel to that applied to the soil at three and twelve months, but very little differences were shown at six months. With potassium applications the highest differential between soil treatments and leaf blades and petioles occurred at six months.

I want to emphasise here, that for physiologists who try to determine the mineral status of plants by analyses of leaves and petioles, they have to be careful about the tisue, and the organ to be analysed at the particular time, in order to get a reflection of the available amount of the mineral element which might be considered to be present in the soil.

The problem of determining the availability of an element by inference from tissue analyses is not an easy one. We have to be careful, and to work out a definite programme for every crop, if we want to secure reliable results.

Mr. de la Pena :

I just want to thank Dr. Sidrak for his very valuable comments, and that is what we are following up from this experiment, because as far as we know we did not have any original information as to the response of this crop to fertilisation, especially with the effects of fertilisation on composition.

In the University, we are running cultural studies in which we are trying to analyse the total plant with the leaves, the petioles, and the nodes that form separately at different stages, so that we can more or less paint a broad picture of the crop itself.

Dr. Samuels :

I want to add a little point to a very valuable suggestion that was made, and that does not only consider the nutrient mineral content and the age and the part of the plant to be sampled, but also the moisture content of what you are sampling.

Our work on sugar cane has shown that the moisture status of the plant has an important bearing on the interpretation of the levels of tissue nutrients. If you use one of the plant organs as a quantitative calibration of the moisture content of the plant you may be able to detect differences by relating this to plant fresh weight. This is particularly true in the case of potassium.

Dr. de Gras :

What I was thinking of the remark of Dr. Sidrak is that when you compare the response of Colocasia and grass you don't compare the same thing, because the length of the duration of one leaf in Colocasia is very much greater than the length of one leaf of grass. When you compare the response for the grass you are comparing something which is very different.

Dr. Wilson :

I would like to ask Mr. de la Pena whether he had any rainfall figures for the upland and lowland conditions.

Mr. de la Pena :

Yes, we had rainfall figures for the upland, but we did not bother to record the lowland, because it had been almost under irrigation throughout the year, and it would be interesting to add that the rainfall in the particular phase which we used, was heaviest about the time of planting, and at the age of 12 to 15 months the rainfall came back again, and just about 8 to 9 months the rainfall was lowest, so that was probably one of the reasons why we had a very low yield in the uplands. The water supply was lowest when the crop probably needed it most.

Mr. Morgan :

I would like to ask Mr. de la Pena about the method of expressing the nitrogen and phosphorus content in these plants. We use percentage in the leaf and I wonder whether this is an adequate method, when you consider, that a small leaf from a whole fertilised or stunted plant might exhibit a high percentage of a nutrient that a larger leaf, which is doing very much better and growing much better from a well fertilised plant.

Mr. de la Pena :

Well, that is very true indeed. We have noticed this too in other experiments that we have run, but since in our particular experiment the nutrients were not very deficient, then we had this increase in nitrogen or phosphorus and potassium content of the leaf. But we also observed that when the crop is growing in a very poor soil, then it just grows to a certain point, and stops at that size, so it maintains just about the normal concentration of the nutrient. This is one of the things that we have to look at when using percentage basis for formulating fertilizer programmes.

That is one reason why some investigators suggest taking the total nutrient content in the plant instead of just in percentage.

Dr. Samuels :

Again I would like to answer this from the physiological standpoint. We who have been studying foliar diagnostic techniques with many crops including sugar cane and pineapples, are aware that a small plant may show an accumulation because of many factors and therefore actully have a high nutrient content. We overcome this by using what we call a vegetative index. In sugar cane we usually obtain the growth or vegetative index by weighing the sheath of the plant each time we sample, so we get a progressive picture of what's going on. In pineapple we do the same thing by weighing leaves. I think that it would be a good suggestion for those of us who are going to start working in root crops to also consider this idea. But, you must remember that the weight must be considered for the actual plant you are working with at that time. You cannot compare weight of leaves, etc. from one variety with another or in one circumstance or another. It is a progressive picture of what is going on in that plant in that particular experimental field.

Dr. de Gras :

I would like to ask Mr. de la Pena if he thinks it would not be very interesting to have a shorter interval between the observation of the growth of the plant.

Mr. de la Pena .

Thank you for this suggestion. As a matter of fact, we have started this on sand culture. We were trying to take plant samples for analysis every week, and we are trying to find the breaking point, because we are also working with deficiency symptoms and we are trying to find the concentration of nitrogen, for example, in the leaf or in the whole plant when the symptoms just start to show. So we are also doing something on this.

THE INFLUENCE OF NPK LEVELS ON THE GROWTH AND TUBER DEVELOPMENT OF CASSAVA IN TANKS[1]

— *by* —

Arnold Krochmal[2] and George Samuels[3]

INTRODUCTION

Methods used in growing cassava (*Manihot esculenta Crantz*) are undergoing changes as the crop shifts from a backyard garden culture to a large scale managed crop. Varying amounts of mechanization (Krochmal 1966) are being adopted and in Brazil and Mexico fertilizers are in use.

To date, little information is available as to the mineral nutrition requirements of this plant. Malavolta *et. al.* (1955) carried out a study in sand culture to find the effects of NPK on the yields and composition of the roots. Krochmal *et. al.* (1955) also worked in sand culture to describe the visible symptoms of major, secondary, and minor elements deficiencies in cassava leaves and to correlate these with chemical analyses of the leaves, petioles, and stems of plants under complete and deficient treatments.

This report concerns nutrient solution tank studies to determine the effects of varying levels of NPK on production of tubers and tops. It was conducted under the Virgin Islands Agriculture Program, of the U.S. Department of Agriculture in Co-operation with Harvey Aluminum, Torrance, California.

PROCEDURE

Three 6 inch cuttings of 'Fowl Fat', a yellow fleshed cassava, were planted in large concrete conduits each 4 feet deep and 18 inches in diameter.

Each conduit was painted on the inside with a mixture of aluminum paint and asphalt, and each had a 1" drain pipe in the bottom. Three cubic yards of No. 3 perlite was used per container.

Experimental design was a random block of 8 treatments and 3 replicates per treatment grown in full sunlight. After 6 weeks the most vigorous plant was kept in each conduit and the 2 others were eliminated. Rainwater was used in preparing Hoagland's Modified nutrient solutions (Table 1) because sufficient distilled water was not available.

Each container received 2½ liters of nutrient solution twice a week; as plants grew additional water was added as needed.

1 This work was carried out under terms of a Co-operative Agreement between Harvey Aluminum, Torrance, California and A.R.S., U.S.D.A.

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Measurements of tuber number, tuber weight, top hieght and top weight were made in May, 1966, at harvest 11 months after start.

RESULTS

Plants grow under high phosphate solution averaged 9 inches taller than low P plants. Other elements failed to show any consistant effect on height. (Table 2)

Table I. Nutrient levels used in the cassava experiment

N	P	K	Treatment identification			Nutrient level in parts per million N	P	K
high	high	high	H	H	H	240	240	240
high	high	low	H	H	L	240	240	40
high	low	high	H	L	H	240	40	240
high	low	low	H	L	L	240	40	40
low	high	high	L	H	H	40	240	240
low	high	low	L	H	L	40	240	40
low	low	high	L	L	H	40	40	240
low	low	low	L	L	L	40	40	40

Tops

The highest weight yield of tops in grams per plant was obtained with the HLH[3] treatment and the lowest was found with the LLH treatment, suggesting that greater top growth was associated with high N levels. This has been reported for cassava (Malavolta et al 1955), sweet potatoes (Landrau & Samuels 1951 and Stino 1953), and sugar beets (Mullen et al 1963). However, the trend was not too strong for all high N vs. low N treatments since the average increase was only 11% (Table III).

Tubers

Phosphorus was necessary for good tuber production. Averaging the various P treatments, we find that high P over low P gave a 93% increase in yield (Table III). In only one treatment, HHH, did the cassava fail to respond. The response of cassava to P has been reported by Malvolta *et al.* (1955) in sand culture and Normanha and Soares Pereira (1949) in soils in Brazil. P is essential for the phosphorylation process in the enzymatic synthesis of starchy reserves in cassava tubers (Malavolta et al 1955).

Production of tubers was severely curtailed with several treatments (Table III). No tubers were formed with HLL treatment and few with HHH.

3 For ease in presentation the abbreviations used in Tables 1 and 2 will be used in the text of this article.

Table II. Influence of varying N-P-K levels on the weight of cassava tops and tubers, fresh weight basis

Treatments[a] N P K	Height per plant, cm	Total weight per pot Tops %	Total weight per pot Tubers %	Average weight per tuber %	Top: tuber weight ratio[b]
H H H	140.1	468	30	30	15.6
H H L	129.5	695	559	241	1.2
H L H	127.0	1000	574	395	1.8
H L L	96.5	423	0	0	0
L H H	114.3	544	574	191	1.0
L H L	144.8	830	908	305	0.9
L L H	96.5	302	136	136	2.2
L L L	109.2	650	155	155	1.8
Least significant differences					
5-percent		293	541	371	
1-percent		449	848	547	

[a] L low H high

[b] Tubers 1 for total weight per pot

Table III. Percent change in yield due to treatment levels of nutrient (NPK) on cassava

Treatment high vs low	Total weight per pot % Tops	Total weight per pot % Tubers	Average weight per plant % Tops	Average weight per plant % Tubers
Nitrogen	+11[a]	−70	+9	−18
Phosphorus	+7	+93	+20	+12
Potassium	−12	−39	−11	+7

[a] Minus sign indicates low outyielded high treatment level; plus sign indicates high outyielded low treatment.

Aside from a definite and significant influence of P, the major effects on tuber yields were brought about by combinations and inter-actions of NP, PK, and NPK. For example, in the presence of high N and low P, high K level gave a significant yield increase of weight of tubers over the low K level (Table II). However, high K did not affect tuber weight if N levels were lowered or P levels raised.

The N effect was the reverse of the P. A 70% yield reduction was noted with high N compared to low.

Many researchers have reported heavy top growth and lowered root and tuber crop yields in pounds per acre associated with high N. Increased N levels result in carbohydrates combining to form proteinaceous materials (tops) rather than polymerizing to form starch (tubers and roots).

The raising of K from low to high levels produced an average decrease in top and tuber weight per pot and a 7% increase in the average weight per plant (Table III). This is contradictory to the finding of many workers who report significant root and tuber yield responses to potash fertilizer application (Ignatieff & Page 1962). Malavolta *et. al.* (1965) also using sand culture techniques obtained much less marked response to K than to P and N. Normanha and Soares Pereira (1949) working in soils in the state of Sao Paulo in Brazil failed to obtain any significant tuber yield response to potash fertilizers for harvests of 9 month old cassava and a negative response for 19 month old tubers. Although we are aware of the essential need for K in the translocation of carbohydrates, the low K levels in this experiment were apparently sufficient for good tuber production as measured by weight of tuber produced per plant.

The average weight per tuber followed the same trends in response to treatments as total weight of tubers per pot (Table II). The N effect showed an average decrease of 30 grams per tuber with increasing N levels. The P and K effects gave increases of 20 and 13 grams respectively, for increasing P and K levels from low to high.

Ratio

The relationship between plants top and tuber weight is always of interest to cassava producers when relating response to fertilizers. A low top: tuber weight ratio is desired for production of tubers; a high ratio would indicate poor tuber production despite an abundant growth of leaves and stems.

The production of tubers was inversely related to the top: tuber weight ratio (fig 1). A decrease in top: tuber ratio to approximately 1:1 appears to be related to high tuber weight production in this experiment.

SUMMARY

Cassava grown in nutrient solution tank studies with various combinations of NPK at low and high levels indicated the following.

1. Only high P increased plant height.
2. Production of tops as g/plant was favored by high N levels and reduced with high K levels.
3. No tubers were formed with high N and low PK levels
4. Increasing N levels reduced tuber growth by 70%.
5. The major effect on tuber yields was due to increasing P levels that raised production 93%.
6. High K levels did not favor tuber production.
7. Greatest tuber production was associated with 1:1 top to tuber ratio and a high P level.

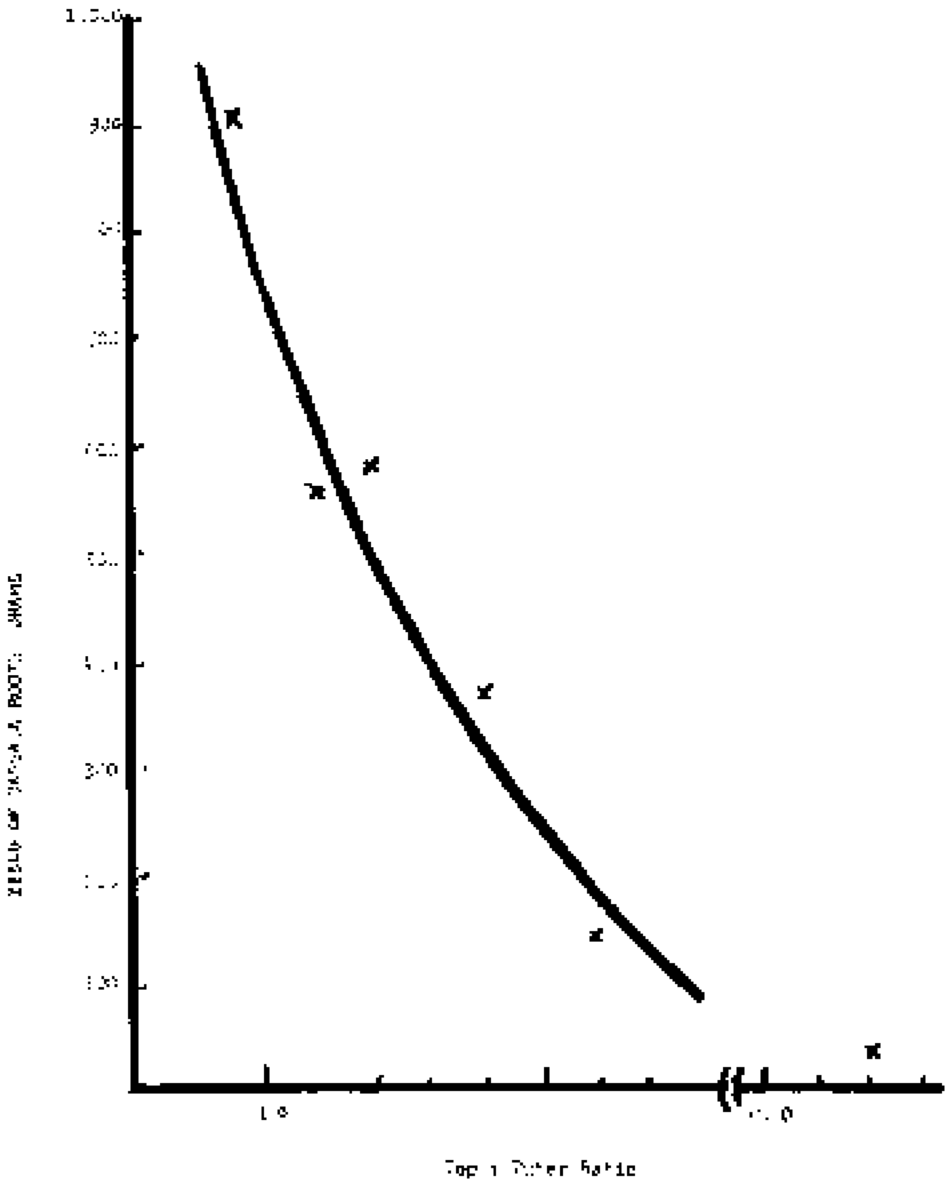

Figure 1. — The relationship of top : tuber ratio to yields of cassava roots.

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CHEMICAL ASSAY OF THE ANTHOCYAN PIGMENTS IN SWEETPOTATO

— *by* —

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Only a very limited amount of information is available on the chemical composition of the sweetpotato, *Ipomoea batatas*(1). Its anthocyanin pigments have only recently been identified as acylated glycosides of cyanidin and peonidin, (2) and some correlation studies have been carried out in connection with the syntheses of carotenoids and of anthocyanins in the stems and tuberous roots of the sweetpotato (3).

The breeding of sweetpotatoes at the University in Trinidad takes into account the need to eliminate a trait which produces purple mottles in the flesh of the tuberous roots. The pigments concerned are the sap soluble anthocyanins which, in comparison with the orange coloured carotenoids, have been little studied quantitatively in the sweetpotato. In quantitative work, any visual assessment of colour intensity suffers from the defect known as the "human element." So only major differences in purple colour intensity are likely to be detected visually in the flesh of any group of freshly-cut tuberous roots, as in the sweetpotato, where the background may vary from cream to yellowish orange. Other significant errors are likely to arise in a method which replaces the human eye with a colorimeter, like the Hunter colorimeter(4), to measure directly the intensity of the purple flecks at a surface.

In this communication, a more objective method is described for routinely assessing the purple pigment concentration in the flesh of sweetpotato tuberous roots. The method proposed should help the geneticist to follow the occurrence of the previously mentioned undesirable trait in the sweetpotato. The method requires a photoelectric colorimeter to determine the intensity of purple colour in a standard solution extract of the plant tissue. A suitable colorimeter using an Ilford spectrum filter is the EEL Portable Colorimeter (manufactured to give an accuracy of about two percent by Evans Electroselenium Ltd., Essex, England).

A whole sweetpotato tuberous root typical of the cultivar under test was sliced in the direction of its growth so as to provide a central section one-eight inch in thickness. This section was considered to be a reasonably good sample of the root with respect to its anthocyanin content. The periderm areas were removed from this section, and then it was finely chopped. A ten gram subsample of flesh material was thus collected and left to stand in the dark overnight, stoppered in a jar containing 100 ml. one per cent aqueous hydrochloric acid solution. This extraction process was found to be efficient, and the absorbance of the filtrate derived was easily measured directly against a blank of one percent aqueous hydrochloric acid, using a suitable filter on the EEL colorimeter (See Table 1). The filtrate gave a maximum near 525 nm (See Fig. 1), so the green filter No. 624 was found the most appropriate for this colorimetric method.

Absorbance readings higher than 0.10 units were found to be associated only with solutions which were visibly pink inside the one-centimetre diameter glass cell used in the colorimeter. Cultivar C9 provided an anthocyan-free extract (See Table 1) and consequently a more desirable colorimeter blank.

The method was extended for preliminary study of the variation of anthocyanin pigment along the stems of a cultivar subjected to a range of growing conditions.

Table 1

Roots of Cultivar	*EEL Absorbance (Units) ± 0.05*
C9	0.10
13/56/5	2.30
13/56/12	4.70
049	0.10
C26	0.10

The tuberous roots contained 70 — 80% moisture.

In this case, the freshly harvested stems (minus leaves) were chopped into two-inch sections at a number of distances measured from their growing points. The average cross-sectional diameter of each two-inch stem section was measured with a micrometer screw-guage, and the length of each stem section was quickly reduced to give each section the same total outer (curved) surface area. Each section was then de-pithed, and the anthocyanin-free pith was discarded. The outer residual straps from similarly located sections of two stems from each agronomic treatment were combined, and each combined lot was left to stand in the dark overnight, stoppered in a jar containing 25 ml. of one percent hydrochloric acid in ethyl alcohol. This extraction process was found to be efficient and provided a filtrate which gave a maximum near 525 nm. (See Fig. 1). So the green filter No. 624 was used, with the acidic alcoholic solution as the blank, in the EEL colorimetric estimation of the colour intensity of the filtrate.

Some results are shown in Table 2 (and Figure 2) for two cultivars 049 and A138. The stems of 049 show no visible sign of pink anthocyanin-type pigmentation, but the stems of A138 are mainly purple coloured to the eye. The method described indicated that the anthocyanin content per unit surface area of the stem of cultivar A138 (at any location up to about three feet away from its growing point) depended upon the conditions of its growth. When growth was encouraged, by the application of nitrogenous fertilisers to A138, the rate of increase of anthocyanin content was suppressed along its stem.

It is likely that anthocyanin synthesis is genetically controlled (3), even though the actual formation (6) of anthocyanin pigments may be dependent on environmental and cultural factors. The production of anthocyanins and other flavonoid compounds (6) seems to depend on the availability of cinnamic acids and other phenylpropane compounds. (See Fig. 3). Studies correlating anthocyanin content with that of certain biogenetically related compounds in the sweet-potato might throw some light on the nature of the intermediate substances produced by plants during the formation of anthocyanins from phenylpropane compounds.

Acknowledgements

Plant material was kindly furnished by the Food Crops Section of the University in Trinidad. The author thanks Mr. D.B. Williams and Dr. J. Spence of the School of Agriculture of this University, for many discussions and their continued interest.

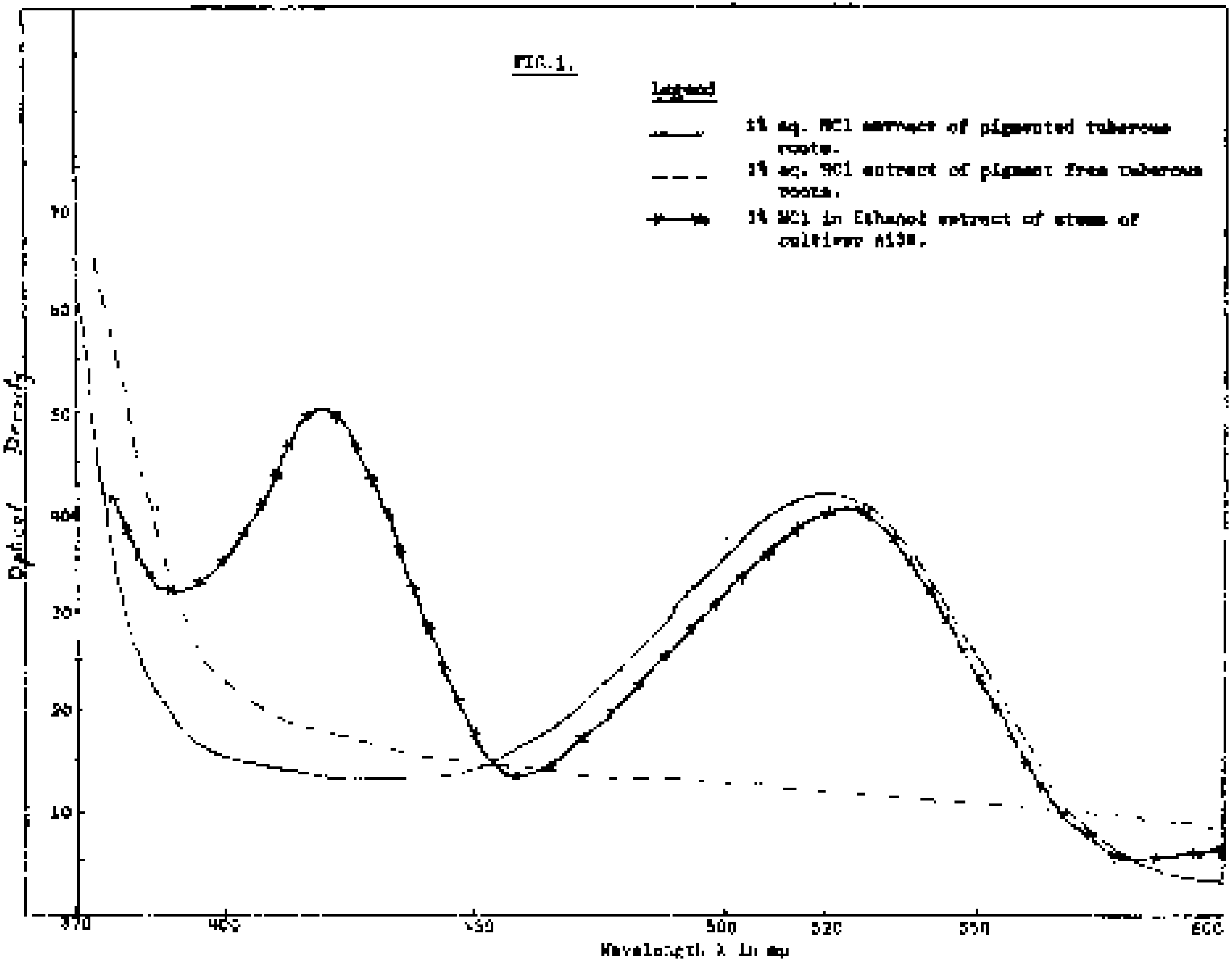

Optical Density
70
60
50
40
30
20
10
370
400
450
500
520
550
600
Wavelength λ in mμ

FIG. 1.

Table 2

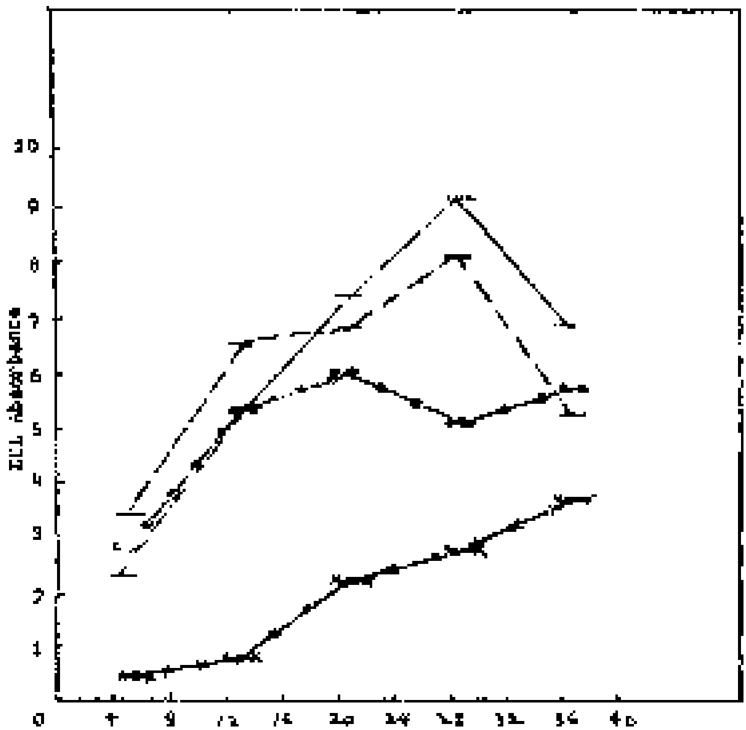
Cultivar	Treatment of Nitrogen and Staking	Diameter in mm. of stem sections		Absorbance units/unit area at locations shown measured from growing point in inches				
		Youngest	Oldest	4"-6"	12"-14"	20"-22"	28"-30"	36"-38"
A138	N_oS_o	4.07	4.37	2.3	5.2	7.2	9.0	6.7
A138	N_1S_o	3.37	4.01	3.5	6.4	6.8	8.0	5.0
A138	N_oS_1	4.09	4 29	2.8	5.2	5.9	4.9	5.5
A138	N_1S_1	3.15	3 32	0.4	0.7	2.0	2.6	3.4
049	N_1S_1	4.35	5.50	1.3	1.0	1.1	1.1	—
049	N_oS_o	4.35	4 20	0.9	1.0	1.1	1.1	—

N_0 – Control (No nitrogen applied)

S_0 – Control (No staking treatment)

N_1 – Nitrogen applied at fixed level.

S_1 – Staking treatment applied.



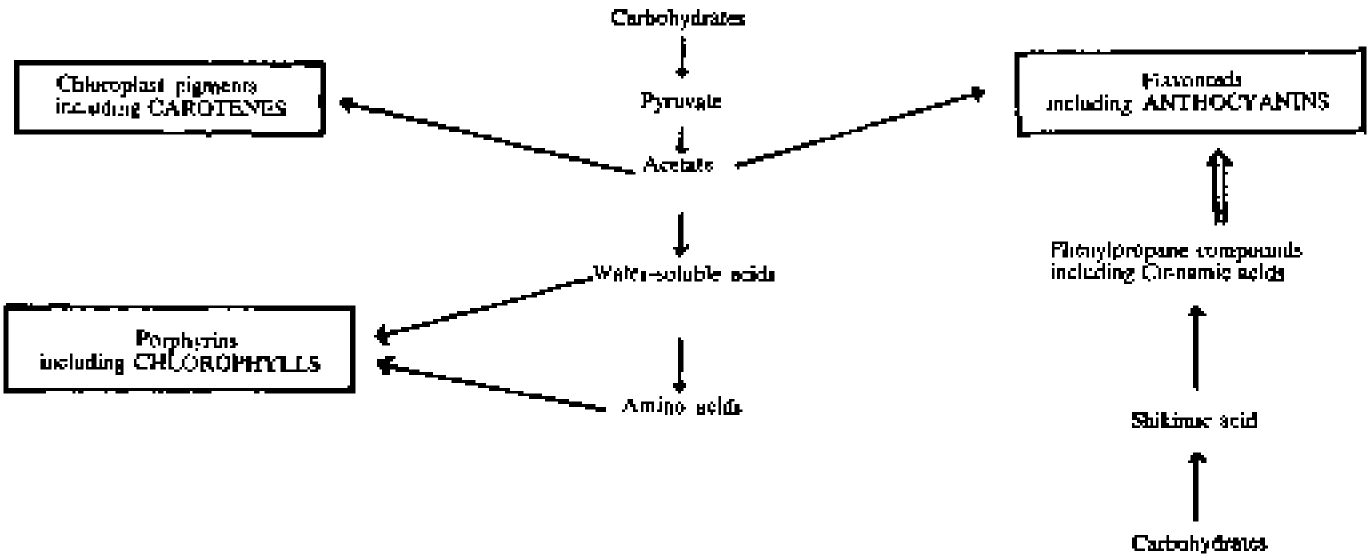
Legend: For Cultivar A138

———	N_0S_0
— —	N_1S_0
o—o	N_0S_1
x—x	N_1S_1

Fig. 3

Sugge

Suggested Biogenetic Schemes for Pigment formation in the Sweetpotato
Cf. Ref. 6. Goodwin (1965)



KEY:

Pathway controls biogenesis of flavonoid compounds

Pathway not specific to flavonoid biogenesis

Pathway may not be entirely specific for pigment synthesis.

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Dr. Carr :

I would like to make a comment on Dr. Seaforth's paper on his method of analysis for anthocyanin. I observed that the absorption at 445 mμ is rather small and I think this is very fortunate. In analyses that I have carried out, the absorption at 445 mμ was tremendous compared with the anthocyanin peak and we had to eliminate the interference effect due to that flavonoid material at 445 mμ by measuring the height of the anthocyanin peak above the base level shown by the dotted line there. If you intend to use a colourless variety as your standard, you would have to be careful that no other flavonoid is being developed by your treatments introducing a large absorption at 445 mμ which would interfere with the anthocyanin concentration readings. And the second point I would like to make is about the relationship of sugar to anthocyanins. Dr. Sidrak, you might not have known about this very recent work at Cornell University. We were able to induce very high levels of sugar in leaves by exposure to low temperatures without producing any anthocyanin, but immediately nitrogen deficiency was initiated by withholding nitrogen from our sand culture solutions we got tremendous amounts of anthocyanin.

Dr. Sidrak :

I would like to ask Dr. Seaforth a question about the anthocyanin production in the sweet potato, and that is it a known fact, and this is work of Teeman some years ago about 1946—1950, in that the amount of anthocyanin although it is affected or controlled genetically, yet it is affected by the accumulation of carbohydrate in particular, sucrose. They have shown that experimentally, and here now I would like just to ask if because of the results here, where we have got the leaves giving nitrogen, the amount of anthocyanins were depressed because of the use of carbohydrates in the make up of the nitrogenous compounds as long as nitrogen is available. I would like to ask Dr. Seaforth if he has tried to determine the sucrose content of these plants which have shown large amounts of anthocyanin production

Dr. Seaforth :

No, I have not.

Dr. Seaforth :

Are you referring to figure 1.

Dr. Carr :

Dr. Seaforth :

Well figure 1 shows that the 445 mu peak is associated with an alcoholic extract and this is why, when you read the paper probably a bit more casually, you will see that the method associated for estimation of anthocyanin in tubers is one using an aqueous, not alcoholic solvent. The alcohol dissolves flavonoids and carotenoids. The 445 mu peak is associated with the carotenoid region, the chloroplast sort of pigment. Between 500—550 mu peak is always associated with the anthocyanin sort so that even though 3 curves appear in figure 1, only two are applicable to the tubers root study, the third one is applicable directly to the stem study because the figure says so clearly.

Dr. Carr :

We used the aqueous HCL extract, 1+1 and the absorption in the 400—500 mu region in the aqueous extract was very high for the material that we used. This was with extracts of leaves. It may be that the sweet potato does not possess these other flavonoid compounds. Have you found tremendous amounts of other flavonoid compounds in the sweet potato material?

Dr. Seaforth :

There are other flavonoids, the leukoanthocyanins and the like, but they should not affect the 440 millimu region at all. The 440 is associated with yellow and orange colours to the naked eye and therefore you must have a water soluble carotenoid there as well. In the sweet potato so far, none of these carotenoids are water soluble. When I say water soluble I mean they would not dissolve in water under acid conditions. You need an alcoholic or soluble solvent sort of thing to extract, then they are chloroplast.

Dr. Carr :

I was talking about yellow water soluble flavonoid compounds, not carotenoid compounds, extracted in 0.1 N aqueous HCL.

Dr. Seaforth :

Well any flavonoid compounds are supposed to absorb mainly if they are pigmented and they are flavonoid. They are supposed to absorb in the 380 plus region rather than at 400 plus. I would like to know what they are, chemically speaking I mean, because all the flavonoid absorption peaks are associated with the phenolic chromophores which are either in the 280 millimu region, which is not visible or the 365 region which, as I said, is associated with flavones, flavonols, flavononols and the like, and then there is a jump, there is nothing in the 400 region normally, except you get a carotenoid and a big jump into the 520 region. There are water soluble carotenoids. I would like to have a look at that again.

Mr. MacDonald :

I would like to make a comment on this purple mottling. It also occurs in Uganda with the sweet potato seedlings but you might be interested to know that in most cases it is associated with mature tubers in Uganda, and the characteristic disappears in the mature tubers at harvest. Only in a very few of the seedlings will you find purple mottling in mature tubers.

CONTENTS

THE USE OF PHYSIOLOGICAL STUDIES IN THE AGRONOMY OF ROOT CROPS

— *by* —

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University of the West Indies., — St. Augustine.

In the past it has been customary to regard crop production largely as a technology. Efforts were concentrated on the actual details of field practice, such as seed and fertilizer rates, planting dates and crop protection technology in relation to yields. Furthermore, much of this practice was arbitrarily determined or adopted because of tradition. The problems that frequently arise by such an empirical approach may be illustrated by reference to nitrogen fertilizer application to sweet potatoes. The literature on this subject indicates conflicting results in the attempts at relating nitrogen application to yield (Stuckey 1914, Zimmerley 1929 and 1934, Leonard and Anderson 1947, Johnson and Ware 1948, Landrau and Samuels 1951 and Stino and Lashin 1963). As will be discussed later in this paper, detailed study of growth and development allows these conflicting results to be resolved (Walter 1966).

Thus agronomy is now seen as a complex of inter-relationships of a system made up of the plant, the soil and the atmosphere. For a proper understanding of this system it must be studied systematically, through the growth cycle of the plant. This approach is useful in identifying the basic physiological processes determining yield in crops and at the same time enables an integrated view to be taken of the growth of the plant which is on the one hand understandable to the physiologist and biochemist in their concern with the changes in rates of processes, patterns of metabolism and influence of growth regulators, and on the other hand this dynamic approach is meaningful to the soil scientist and the micrometeorologist in their study of environmental influences on crop growth. This dynamic approach does not neglect agronomic technology but allows its assessment on a more fundamental basis. Thus planting densities, potential for response to fertilizer and other agronomic parameters are studied as they relate to growth and development throughout the full growth cycle. Studies of this nature have been carried out on many temperate crops, but information on tropical crops is scarce.

In most of the studies discussed in this paper, growth analysis, that is the designation of dry matter changes of component plant parts in relation to leaf area, is used to describe the growth and development of the crops. In these growth analysis studies the crop system is considered in terms of the quantity of the photosynthetic system present and in terms of the efficiency of this system. The quantity of the photosynthetic system is here taken to be represented by the leaf area of the crop, measured as leaf area index, L, the area of leaf per unit area of ground, and the leaf area duration, D, that is the integration of L with time. The efficiency of the system is measured as the Net Assimilation Rate — E, that is the rate of dry matter production per unit area of leaf.

The relation between L and E have been discussed by Watson (1952). In this paper our concern is primarily with the influence of leaf area development on yield. Our studies with tropical root crops have so far confirmed the view that L has the greater influence on yield and is of greater concern to the agronomist than E since it is more easily altered by field practice. The ready response of L to such factors as rainfall and nitrogen fertilizer are indications of the ease with which changes in L may be achieved. Changes in L are not easy to control and their effects on yield vary with the system of cultivation.

The basic growth patterns (as far as these are known) of yams (*Dioscorea alata*), sweet potatoes (*Ipomoea batatas*), tuberosum potatoes (*Solanum tuberosum*) in the lowland tropics, are described and this knowledge is discussed in relation to formulation of agronomic practice. Reference is also made to tannia, (*Xanthosoma sagittifolium*.)

GROWTH AND DEVELOPMENT PATTERNS SELECTED ROOT CROPS AND SOME AGRONOMIC IMPLICATIONS

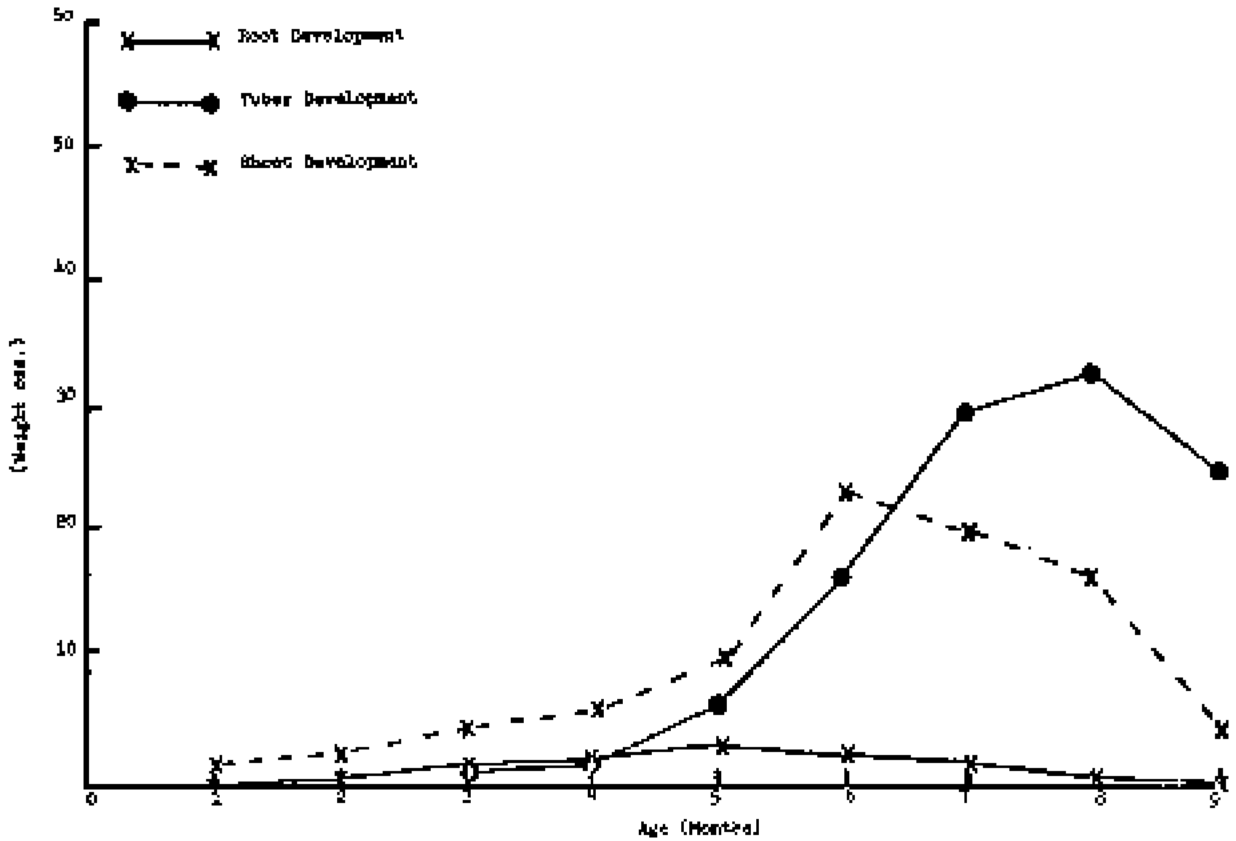
Yams

Of the many yams grown for food in the tropics studies of this crop at the University of the West Indies have been limited to the "White Lisbon" cultivar of *Dioscorea alata*. The earliest account of growth and development studies with this crop was that of James (1953). In this study observations were restricted to root and tuber development and little data was collected on leaf and stem development. It was observed that initial root development was superficial, being confined to the upper 4 ins. of the soil. It was also shown that fibrous root development reached a peak in the fourth month after planting, and that senesence of these roots had commenced by the fifth month. These observations pointed to the possibility of damage due to mechanical weeding during early growth of the crop, and to a reduced potential for absorption of nutrients after the fifth month of growth.

Yam tubers show a regular sequence of dormancy and growth. The tubers remain dormant for 3-4 months, depending on the cultivar, and growth lasts for 8 or more months. The sequence of growth and dormancy leads to periods of availability and shortage. In a series of investigations on the mechanism of dormancy, Campbell et al. (1962) showed that sprouting of yams was related to the level of glutathione present in the tuber. It was further shown that the glutathione level could be increased by treatment of yam tubers with 2-chlor-ethanol. This treatment permitted sprouting of yams to commence and enabled yams to be planted as early as March. It then became possible for the trends in growth to be followed for successive monthly plantings starting in March and ending in June. Such a study was reported by these workers but no dry matter measurements or leaf areas were determined and only fresh weight measurements were recorded for roots, shoots and tubers. The growth and development patterns for this crop at the different planting dates were based on these fresh weight measurements (Fig 1). These curves showed little difference in character with month of planting, and indicated that the production of yams could be staggered if the crop was planted on different dates. The peak development of roots observed by James (1953) was confirmed, and it was noted that shoots attained maximum development six months after planting thereafter showing a decline. Rapid tuber development commenced about five months after planting in all cases except for those planted at normal date (mid-May), in which case rapid development started in

Fig. 1 Fresh Weight growth for Yams (roots, shoots and tubers) planted in early March · Taken from Tsai & 1956.

March Planting



the fourth month (Fig 2). Maximum fresh weight increase was attained by the eighth month in every case. By the ninth month the crop had matured. In the same series costing trials on the out of season production of yams was attempted (Ho-A-Shu 1958) by breaking dormancy with 2-chlor-ethanol treatment and growing the crop with irrigation. Recently commercial scale out of season production has been carried out with a good measure of success (Haynes and Thomas 1967).

Using the data collected by Teriba (1958), Campbell *et al.* (1962) suggested that nitrogen fertilizer could be more effective if applied 3 months after planting. This was subsequently confirmed by Chapman (1965 a) who showed that nitrogen applied three months after planting gave a greater increase in D and in yield than in those cases where application occurred at planting. It was suggested that since planting was carried out immediately before the onset of heavy rain there was a strong likelihood of losses of nitrogen due to leaching and in any case there may be a sufficiency of nitrogen in the soil due to dry season mineralisation (Birch 1960). On the other hand a delay in application of nitrogen beyond five months is unlikely to lead to its efficient utilization by the plant since roots begin to decline about this time.

In Trinidad yam vines are grown on supports. This is indicative of the response to better foliage display in this crop. The increase in yield due to staking of yams is well known (Burkhill 1920, Wood 1933, Campbell and Gooding 1962, and Gray 1962). It is, however, only recently that a study of the leaf area and yield relationships of yams grown with stakes have been described here (Chapman 1965 a) (Fig 3). This description is however general and the differences between staking and nitrogen treatments are not shown. In this study (Chapman 1965a) it was observed that plants grown on long stakes gave higher yields than those grown on short stakes. Differences in leaf duration were noted between yams grown on 3 ft. and on 6 ft. stakes, but these differences were not statistically significant. A further investigation of level of nitrogen and staking confirmed the effect of increased yield due to staking and suggested that stakes enhanced the effect of nitrogen application.

It is however felt that a comprehensive study of growth and development of yams is still needed, such studies are in progress in Guadeloupe (*c.f.* Degras, this Symposium) and in Barbados (Gooding and Hoad 1966). It is hoped that from these studies a better understanding of the leaf area/yield relationships will emerge.

Sweet Potatoes

In attempts to characterise leaf area development in sweet potatoes the dependence of leaf area on environmental and management conditions becomes clear. Such factors as nitrogen fertilizer level, provision of supports (staking) and spacing, alter the leaf area development curve and influence yield. The available evidence suggests that there is an optimum curve of leaf area development with which maximum yield is related. This hypothesis does not deny the influence of leaf display on yield nor that E may vary with cultivar or fertilizer level. It is contended, however, that the difference in yield due to leaf display and E are small, relative to the effects on yield due to leaf area development. It is also contended that fertilizer treatment and other agronomic practice are only capable of influencing yield within the limits determined by the leaf area curve. Based on these assumptions our recent work has been concerned with varying L and relating yield to these variations. This type of analysis has been made easy.

Fig. 2 Fresh Weight grams for Taro (roots, shoots and tubers) planted at normal date (Mid-May) - Taken from Terike 1958.

Normal Planting (Mid-May)

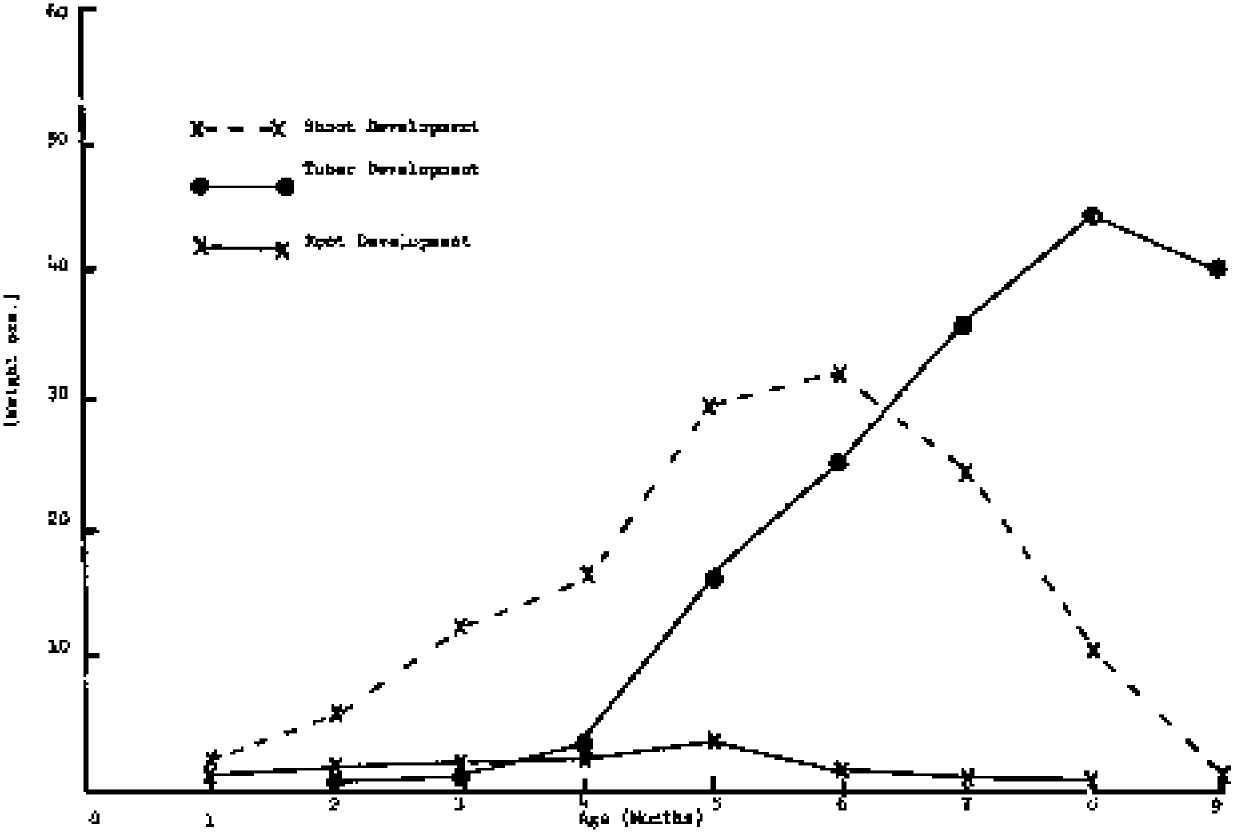
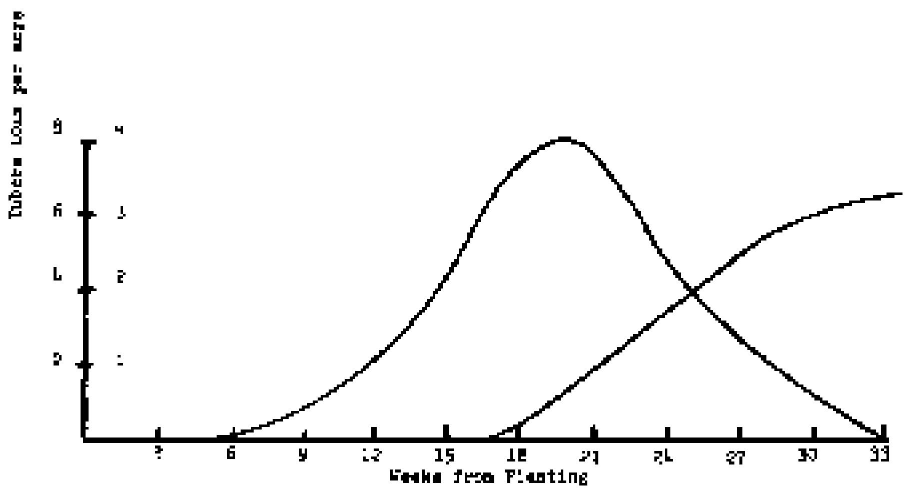


Fig. 1 Leaf area and tuber development in yams - a generalized version. Taken from Chapman 1965 a.



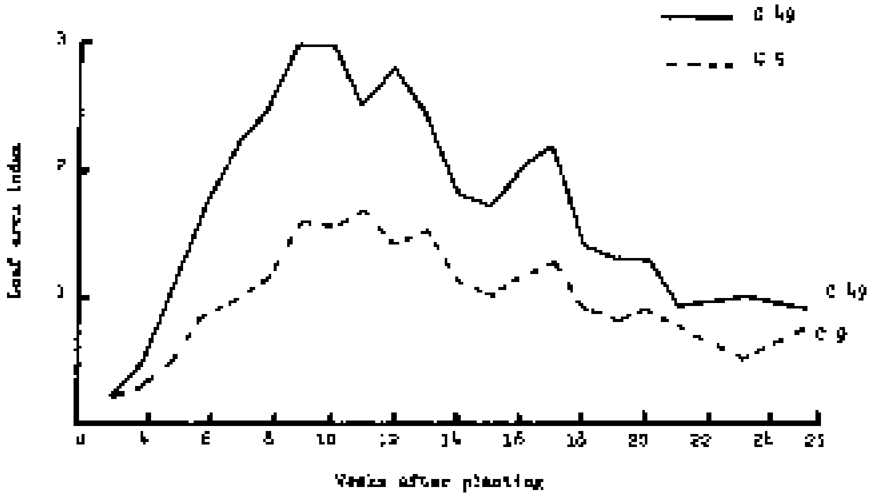
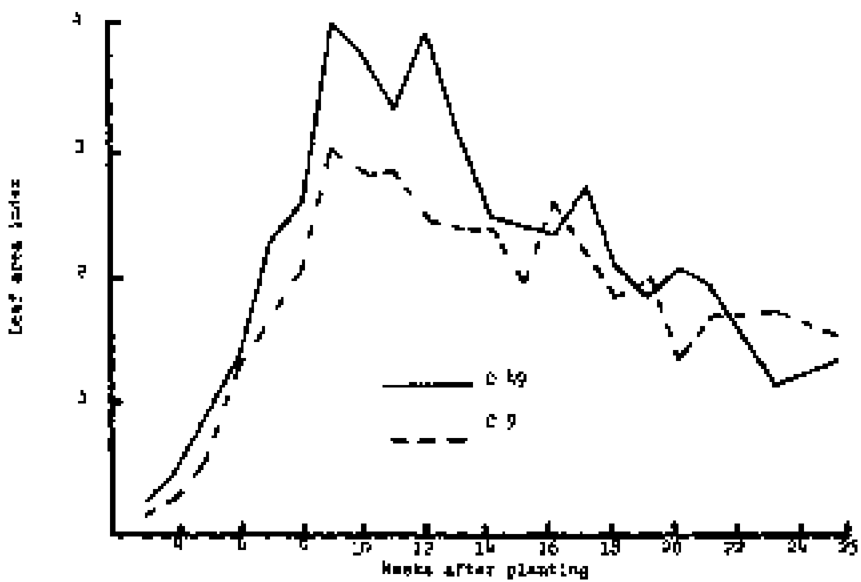


Fig. 4 Leaf area development for C 9 and C49 at zero level of nitrogen.

Fig. 5 Leaf area development for C 9 and C 49 at 120 lbs nitrogen per acre.



by the availability of a range of cultivars with differing values of L. It was therefore possible to select on the one hand a cultivar with relatively low L but possessing high tuber yield such as C9, and on the other a cultivar with high values for L and high commercial yield 049. By varying the levels of nitrogen fertilizer an increasing range of leaf area values for both cultivars was achieved and the resulting dry matter accumulation from these leaf area values assessed (Walter 1966). The responses to 0 and 120 lbs. of nitrogen per acre are shown for 049 and C9 in Figures 4 and 5.

It is interesting to note the similarity between the leaf area index curve for C9 at 120 lbs. nitrogen per acre and that of 049 without nitrogen. This is in contrast to the curve for C9 without nitrogen which produces low L and low yield and the curve for 049 and 120 lbs. nitrogen per acre which produces excessive L and a low yield when harvested at the normal time for the commercial crop at 4 months.The response of 049 with high nitrogen deserves further comment.

The curves for tuber dry weight with 049 (Fig 6) and (Fig 7) C9 at 0 and 120 lbs. nitrogen show contrasting effects of nitrogen for the two cultivars. In the case of 049 the higher level of nitrogen depresses tuber production in early growth. The subsequent rate of tuber development becomes rapid after the leaf area shows a decline. It is suggested that L in the first 12-14 weeks is excessive but during 16th-20th weeks when it is presumably nearer to the projected optimum, the rate of tuber bulking is rapid. The effect of this late and sustained development of dry matter gives rise to the possibility of higher ultimate yields from the high nitrogen treatment of 049, provided harvest is delayed beyond the arbitrarily selected 4-month growing period for this crop.

In an earlier paper (Spence and Haynes 1966) these results are discussed in connection with the breeding of high and low nitrogen response varieties. Tsunoda (1965) has also designated low response and high response (to nitrogen) varieties of sweet potato, the former having a high leaf area under low nitrogen levels and the latter having a low leaf area under low levels of nitrogen. In the low response varieties the application of nitrogen raises the leaf area above the optium level with resulting mutual shading of leaves and reduced photosynthetic efficiency.

Tsunoda does not point to the compensating effect in the later stages of growth, of low nitrogen response varieties with high nitrogen treatment when L has fallen below maximum, but this may be due to restrictions imposed on the length of the growing season by climatic conditions in Japan. Trials in which the efficiency of display of canopy is improved (Chapman and Cowling 1965) indicate that the projected optimum L varies with display. The plant appears capable of maintaining L at a higher level without loss of efficiency in tuber production. This effect has been demonstrated (Chapman and Cowling 1965) using the cultivar A138 which normally produces high L and low yield. However, when the canopy is displayed on supports there is a marked increase in L and in yield. By addition of nitrogen to the supported plots further increase in L and in yield were obtained. It seems clear from this study that the idea of an optimum L must be related to the system of cultivation.

Variation in plant spacing provides another means of influencing leaf area. In a projected trial it is intended to vary the spacing at which cultivars with high

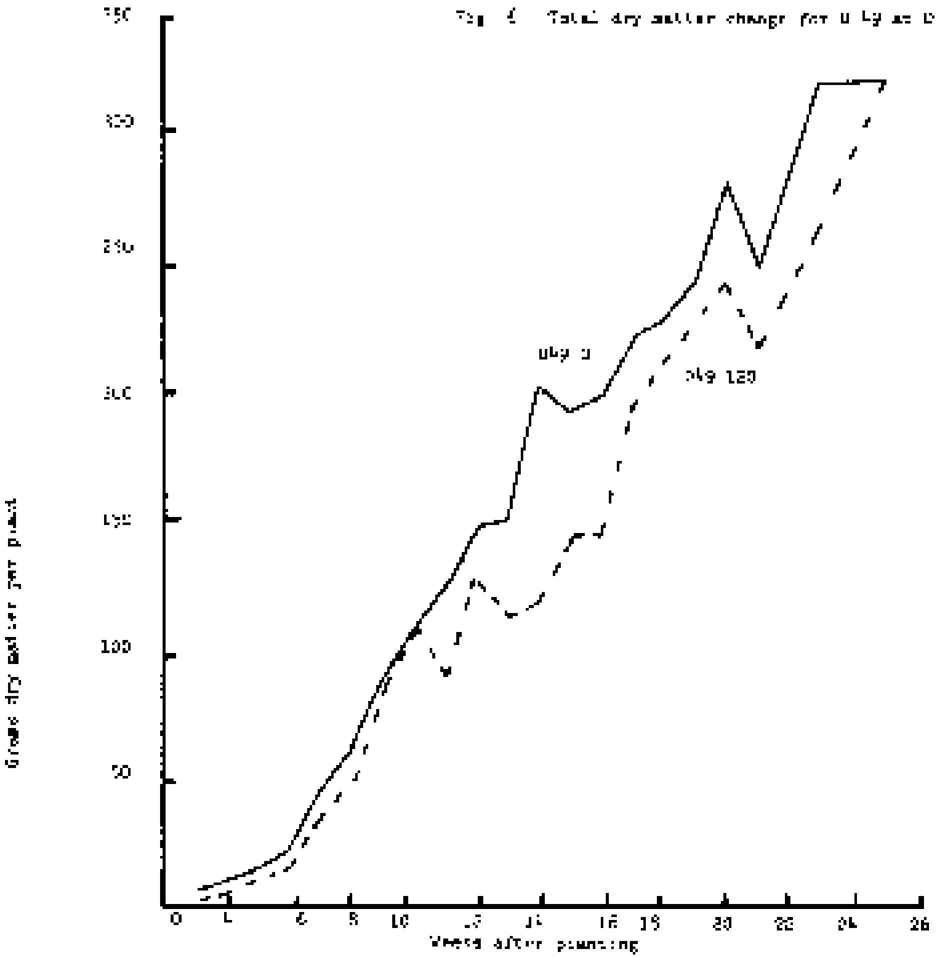
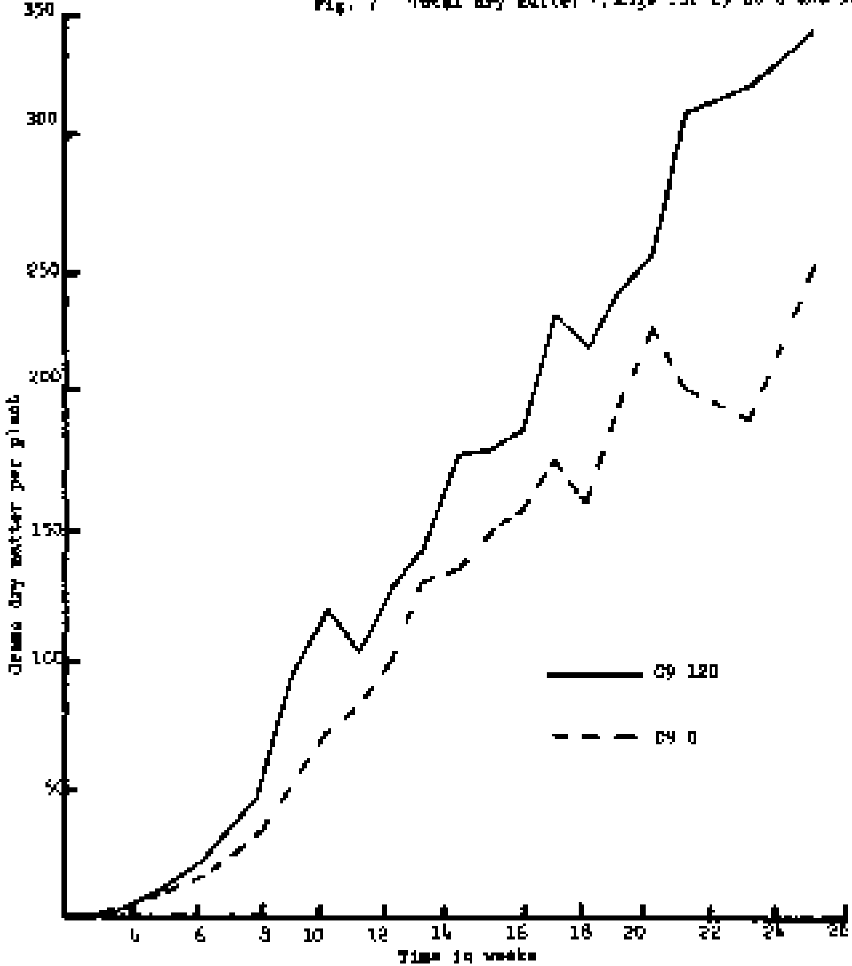


Fig. 4. Total dry matter change for U 49 at 0 and 120 lbs nitrogen per acre.

Fig. 7 Total dry matter change for C9 at 0 and 120 lbs nitrogen per acre



and low leaf areas are grown, and to assess the leaf area/yield relations which result from these manipulations. It is likely that cultivars with high L grown at close spacing would produce excessive leaf area and a lower yield. On the other hand, the cultivars with low leaf area may be grown at a closer spacing and might still be expected to produce a higher yield.

It is suggested that the leaf area development of sweet potato cultivars is influenced by nitrogen, foliage display and spacing and that there is an optimum L for a particular foliage display system. It is further suggested that cultivars may have equal maximum yield potential but that different systems of growth may be required to express this potential. In this connection the economic feasibility of the system must be considered. For instance, in a labour intensive system cultivars with large leaf area may be grown on supports, whereas in a labour extensive system a low leaf area cultivar grown at close spacing may be a more appropriate choice. Similarly, in areas remote from the manufacture of chemical fertilizer, use may be made of cultivars capable of producing a large leaf area when grown in the absence of nitrogen fertilizer. On the other hand where fertilizers are readily available and their cost is low, cultivars with low leaf area may be used and nitrogen fertilizer applied.

Tuberosum Potatoes at Low Elevation in the Tropics

The growth of Irish potatoes at low evaluation in the tropics is characterised by a short growing period and high rates of tuber production, about 11 tons of tubers in about 13 weeks (Chapman 1965 b) (Fig 8). On the basis of yields of this order in so short a period of growth, the tuberosum potato would seem to be efficient compared to other tropical root crops. A yield of 11 tons per acre of sweet potatoes with the cultivars now in use in Trinidad might take from 20-24 weeks and about 36 weeks for yams or tannias so that, thinking in terms of production per acre, per annum this would seem to give a tremendous advantage to the tuberosum potato, provided varieties can be found which will give similar yields in the warmer season.

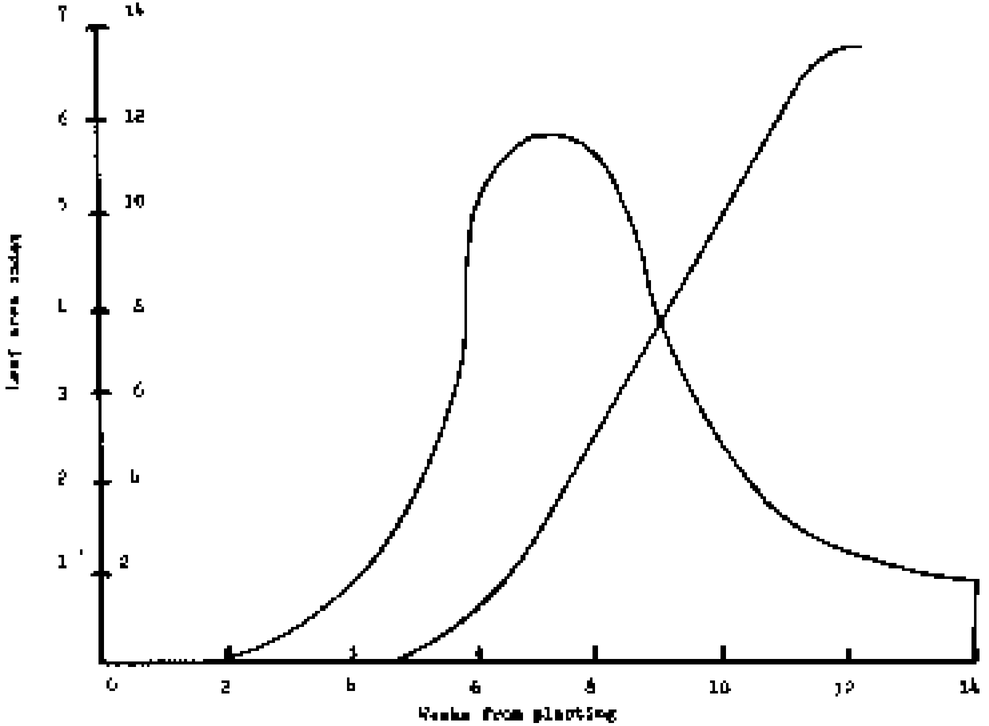
Due to the short crop period, attention is focussed on the patterns of leaf area development in this crop and on possible means of extending leaf area duration. Chapman (1965 b) also showed that nitrogen increased peak value of L and maintained L at a higher level until maturity. Although these peak values of L coincide with the period of maximum tuber development they are maintained for only a short period of this phase of tuber development. These data are in accord with the view that important increase in yield of this crop could accrue to treatments which served to maintain L at a high level (Bremner and Taha 1966). The application of nitrogen at planting is by itself inadequate and it has been suggested (Haynes 1966) that top dressing with nitrogen at seven weeks or spraying urea on the foliage is worth investigation.

Tannias

This crop is capable of progressive growth for long periods and is usually terminated because of shortage of soil moisture or because it is commercially advantageous to reap the cormels.

The natural disposition of the foliage of this crop to sunlight is such that there is apparently little competition within the plant for radiant energy. There

Fig. 8 Leaf area and tuber development in tuberosum potatoes after Chapman 1965 b.



would appear to be considerable scope for increasing leaf area through the use of nitrogen fertilizer and through closer spacing. The ease with which leaf area can be determined (Chapman 1964) recommends this crop as a convenient subject for study in field experiments, where changes in leaf area development are brought about by agronomic practice.

CONCLUSION

In the present paper the value of growth analysis is emphasized though recognition is also given to the fact that a knowledge of the morphology of the plant may influence agronomic practice. For example the superficial nature of yam roots was discussed in relation to mechanical weeding. Also, the necessity to seek an understanding of biochemical processes within the plant, in addition to the approach of growth analysis is indicated by the work described on breaking of dormancy in yams.

The limitations of the traditional approach in agronomic practice where treatment differences are assessed after a given period of time is illustrated by the conflicting reports on the response of sweet potatoes to nitrogen fertilizer. The value of a knowledge of the growth and development of the crop in understanding the effect of nitrogen fertilizer when applied at differential rates becomes evident in studies like that of Walter (1966) which has helped to clarify the nitrogen response (or lack of response) in this crop.

Using evidence from the work on sweet potatoes, the hypothesis is put that optimum yield is related to a given leaf area curve. The effectiveness of a given leaf area is related to its display and so optimum leaf area curves must be related to specific systems of culture. This leads to the contention that agronomic practice should vary with the level of technological input which is itself influenced by the economics of production.

While further evidence is needed for yams it seems likely that the same general principles will apply. In the case of tannias the system is simpler since the laminae have a simple display and the morphology of the plant will not allow the altering of this display by agronomic means.

The emphasis placed on L in this paper is in no way intended to minimise the importance of differences in E. Many of the factors affecting E will be discussed in other papers in this Symposium (Humphries, Wilson). Also it is not intended to minimise the importance of growth regulating substances such as a tuber initiating substance in the tuberosum potato (*c.f.* Milthorpe, this Symposium) or the effect of potassium fertilizer in many root crops. But in the present state of knowledge of tropical root crops it would seem that agronomic practices will have the greatest effect on influencing yields through their influence on L.

It is clear that plant breeders who provide the characteristics of the plants to be grown should bear the several circumstances of agronomic practice in mind when breeding new cultivars. If in this way material is produced with highly contrasting leaf areas (low or high) their yields may be maximised in both types by the varying practices which are possible at the different levels of production.

ACKNOWLEDGEMENTS

As is evident from this review, a number of research workers of the Imperial College of Tropical Agriculture and later the University of the West Indies, in Trinidad have contributed to our present state of knowledge of the physiological aspects of root crop agronomy, and the authors acknowledge their debt to all these researchers whose endeavours have made their present review possible.

The authors would also like to express their gratitude to the editors of Tropical Agriculture for their permission to reproduce figures. Figures first published in the Empire Journal of Experimental Agriculture are acknowledged. Acknowledgement is also given to the assistance provided by Mr. D. B. Williams with the work quoted under Walter (1966).

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GROWTH AND STORAGE IN TROPICAL ROOT CROPS

— *by* —

L. M. Degras

Yam (*Dioscorea*), Sweet Potatoes (*Ipomoea*) Tannia and Eddoes (*Aroids*) are three staple food crops in the West Indies as well as in some other tropical countries. Our knowledge of their biology does not permit a rational basis for varietal improvement.

The well-known research of the Trinidadian School (Brown 1931, Oyebug 1955, Gooding 1960, Chapman 1964, Cowling 1965, Haynes & Williams 1965, Spence & Haynes 1966), the Mayaguez staff (Martin et al 1963, 1966), the Japanese research workers (Tsunoda 1959, Tsuno and Fujise 1964, Yuan 1966), the American geneticists (Poole 1955, Hernandez, Miller 1964, 1966) and, also, less known publications of some West African agronomists, have thrown an interesting insight into many aspects of their biology. We are not still able to set up an integrated presentation of their biological facts which might lead to a sound breeding policy. Though empirical selection could produce valuable varieties, it is evident that some combined and speculative approach will ensure maximum progress in this field.

Calorific value of root crops is linked with dry matter production. So yield is directly dependent on synthesis, transport and accumulation of dry matter. The appraisal of these processes for breeding bears on the morphological and physiological determinants of yield. The concepts of Gregory, Watson and others (see V. Stoy 1964 and Spence & Haynes 1966) led to the use of growth analysis in terms of leaf area and the relation of this area with duration and density of the crop. Through Milthorpe and Ivins (1963) and other works revised by Moule (1960) and Jumard (1964), it appears that the specific physiology of the storage sites plays a dominant role at least in some phase of dry matter accumulation. It is on these lines, morphological and physiological, associated with leaf and root storing processes that the following observations have been undertaken.

Limitation in the set of results expected has been introduced from a hurricane in September 1966. No attempt will be made here to conceal the lack of extensive support of some tentative conclusions.

I. Yield and Dry Matter Storage in Sweet Potatoes, Yam, Tannia.

1. *Yielding Capacity*

Table I shows three orders of yield obtained with these root crops. The final order of yield obtained (column 5) has been taken as indicating yield potential or productivity of the crop. Nothing is truly new in these facts. But speculating on the factors on which rational selection should be based with a view to ensuring productivity is an interesting prospect here. Crop duration as determined by a number of economic and technical reason should be shortened through selection, at least the control of environment permits to extend it. Shortening of crop duration generally is subject to certain limitations unless there is a modification in the storing processes. The well-known empirical method of selection for fresh weight yield has already been questioned because of its complex nature being dependent on morphological and physiological components. If we examine the average of each factor at each level of yield we observe that the variation of percentage of dry matter is the only one agreeing with that of dry matter yield per day of crop duration. Thus, percentage of dry matter remains the basic way by which crop duration and fresh weight yield should be measured.

2. *Yielding efficiency*

Capacity of storing dry matter is primarily dependent on progressive redistribution of the photosynthates between structures for future synthesis and sites of accumulation. Figure 1 brings together interesting features of this distribution in the crops observed:

(1) General participation of exponential curves in these growth relations,

(2) Dependence of yielding efficiency on either,

(a) ecological situations (Sweet Potatoes No. XI for two years)

(b) varietal behaviour (Tahiti and Couleuvre Yams)

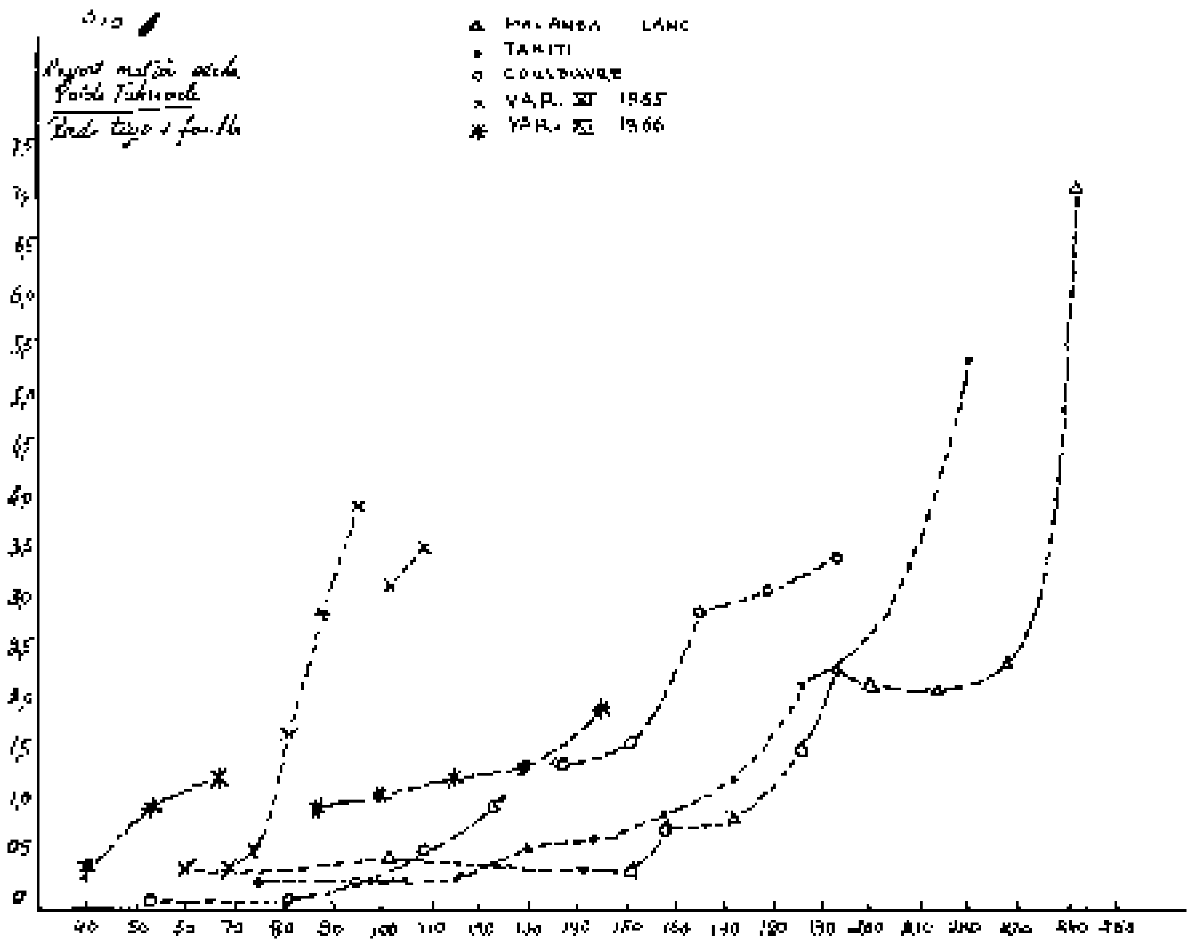
(c) stage of growth (no linearity of the ascending curves).

The occurence of exponential curves here, though not published in our knowledge elsewhere, for these root plants, needs not too much explanation since Gregory and Blackman's classical presentation of growth rate. Yet, the modalities we see suggest definite stages of growth regarding shoot-root relations. The departure from true exponential curves in Sweet Potato can be accounted for by the limitation of material for sampling.

Table I. Relevant factors of yielding capacity

Varieties	Crop Duration (Day)	Fresh Weight (T/ha)	D.M. (%)	D.M. Yield (Kilo/ha/day)
Tahiti	220	32.0	31.0	
	(157)	(21.8)	(34.1)	45 (High)
Sweet Potato No. XI	95	11.7	37.3	
Couleuvre Yam	193	22.5	34.0	
	(196)	(24.0)	(32.3)	39 (Medium)
Tahiti Yam	200	25.6	30.7	
Sweet Potato No. XI	129	5.0	34.2	
	(185)	(9.0)	(29.0)	13 (Low)
White Tannia	242	13.1	23.9	

(See the text ch. I, 1. Number in bracket is the average).


TAHITI
VAR. 1965
VAR. 1966

II. *Storing Process in Couleuvre Yam (D. alata)*

The fact that Couleuvre Yam possesses a certain number of intermediate characteristics leads one to envisage a possible scheme for the storing process in this variety. Figure 2 permits comparison of six curves, the meaning of which we stress here:

A. Net assimilation rate (E) in grams per square decimeter per two weeks (between two samplings) for the whole plant.

B. Relative growth rate of root in percentage of dry weight of existing tuber.

C. Growth rate of root relative to the leaf area (same unit as A).

D. Relative growth rate of leaf area in percentage of existing lamina surface.

E. Leaf area per plant.

F. An index of light interception intended to take account of the part of the leaf canopy reaching compensation point (Tsunoda 1959, Saeki 1963, for instance). This index has been tentatively calculated through leaf area divided by fresh weight of vine.

Let us compare the curve A (E) and B (percentage tuber growth). The major discrepancy rises from 81 to 123 days after shooting, another less important one being placed at the end. There can be no doubt that this discrepancy from the proper course of tuberisation is due at the beginning to its initiation, and at the end, to dormancy. In other instances E goes on a line sufficiently close to that of tuber growth.

Now let us compare E (A) with the curve C relating tuber growths to leaf area. Around the 123rd day the two curves reverse their positions. Clearly, this signifies a change in the immediate source of dry matter entering the tuber, the amount of dry matter actually photosynthesized being insufficient for its enlargement. From this time, dry matter consumption of stem storage is necessarily beginning. But, one can notice that curve C variations remain in relation with those of E. This may be understood as E being a limiting factor of tuber growth.

The reversal of curves A and C would be surprising when considering the concurrent ascending curve of leaf area, if the correlative elevation of the index of light interception did not suggest a possible contribution of lamina ageing at the same time. Climatic circumstances could also support this interpretation.

Summarizing the main facts, it can be said that the storing process in Couleuvre Yam is the joint effect of tuberisation (initiation and dormancy) and lamina dry matter synthesis (and loss).

III. *Structure of the Leaf Canopy and Yielding Ability in Sweet Potatoes.*

As may be seen from Figure 3, each crop offers a definite relation between lamina dry weight and stem dry weight, the general ranking being Yam, Tannia (petiole instead of stem) and Sweet Potato.

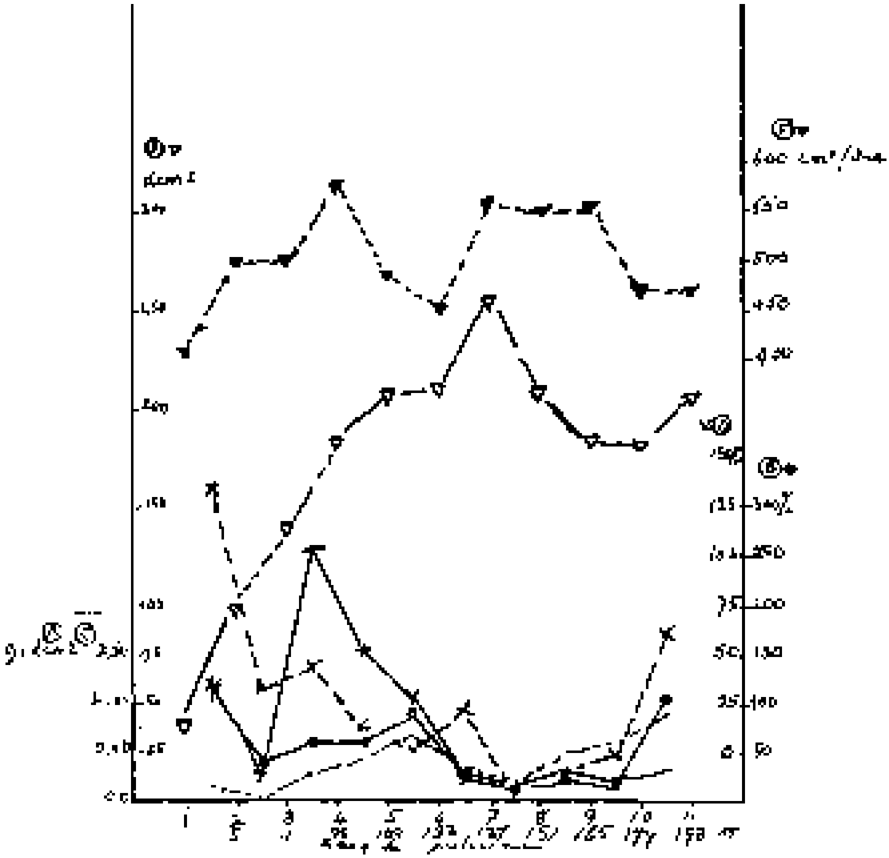


Fig. 2

EVOLUTION DE LA SURFACE FOLIAIRE
ET ACCUMULATION DES RESERVES
CHEZ L'IGNAME COULEUVRE

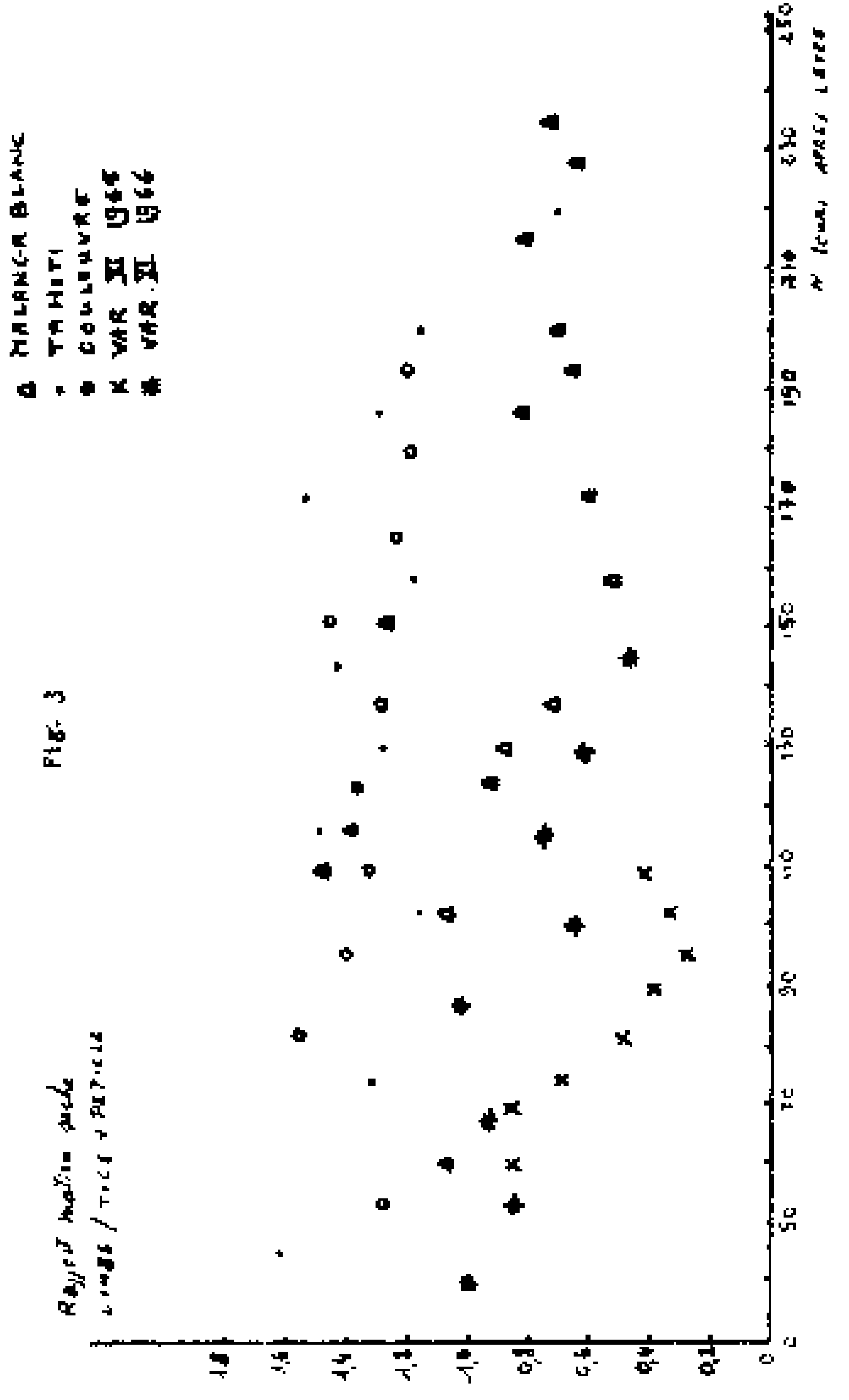


Fig. 3

For this last crop a deeper investigation must be reported. Assuming the well-known importance (Tsunoda 1959, Brougham 1958, Saeki 1960, and others) of lamina surface (S), lamina and petiole relation, in weight (Lw, Pw) and length (Ll, Pl), density of leaf along the stem (Ld), we observed their combined value among five Sweet Potato varieties which had been cultivated in trials for two years:

Parameters	*Assumed intervention in yielding ability*
S	Positive
Lw/Pw	Positive
Ll/Pl	Negative
Ld	Positive
S x Ld	Positive

The ranking of the five varieties for each parameter is shown in Table II, and also the conventional summation of these ranks against the average yield obtained from the two years. The adequacy of this comparison at least, encouraging. It would be even better if we have had dry matter estimation; see the number in brackets calculated on the basis of one year dry matter percentage. It stresses both the interpretative value of the physiological assumptions and the possibility of a selective approach of a sufficient wide range of yielding ability through morphological examination.

Indications not considered here give additional outstanding interest to these parameters for morphological seriation among ten studied varieties.

Table II. Leaf canopy structure and yield in sweet potato

	Rank for Parameters						Average Plot Yield
Varieties	S	Ld	S x Ld	Ll/Pl	Lw/Pw	Total	(Kilos) Total
XI	3	1	3	1	1	9	91 (33)
IX	4	1	1	3	3	12	60 (22)
VII	2	3	4	5	1	15	52 (18)
III	1	4	5	1	5	16	38 (13)
X	5	5	2	4	4	20	51 (14)

(see text Ch. II, 2.)

IV. *Tuberisation and Yielding Ability in Sweet Potatoes*

Periodic sampling of ten varieties of Sweet Potato over a nine month trial culture set forth the determining value for yield of early tuber bulking in a given environment.

Planting was carried out at the end of September 1965. Shoot-root/fresh weight ratio has been considered from the 75th to the 171st day. Harvesting was carried out in relation to tuber development and, in the different varieties, extended from the 171st to the 285th day.

The range of relative tuber development is maximized at the 154th day. If one relates yield capacity (total yield divided by duration of the crop) to total tuberisation, a double line of correlation between them seems possible. (Figure 4).

V. *Conclusions*

Rather than outstanding results in the field concerned, it is hoped that a useful methodology may come out of these observations. It lies in two general views relating growth investigations with breeding for yield in our wet tropical countries.

1. From the growth curves of the three root crops presented as well as from the first analysis of yield factors in a set of varieties, it appears that common principles can be found, brought out by a study of the particular factors responsible for the distinct but homologous series.

Thus, we notice the general intervention of sequences of exponential curves. The question arises of the nature of the phases concerned which can be analysed through their limiting factors and level of their intervention. Seemingly, in our *Dioscorea* culture modification of the immediate source of root dry matter may account for a distinct phase of growth. However, it remains that within each phase primary and somewhat common factors to be determined will explain the curve evolution.

On the other hand, the possible existence of two series in the relationship between yield and earliness of tuberisation in our Sweet Potato varieties denotes common determining factors with the exception of a given transposition factor, not yet identified, but thought to lie in morphological structures.

2. All these observations lie in the direction of physiology and morphology of growth. There is also as has been already discussed genetical implication of growth in breeding for yield. But we must now emphasize basic biological knowledge lacking in the current appraisal of tropical root crops. Every one is convinced that in wet tropical countries speciation has led to proliferation of many forms more adapted to vegetative reproduction than to seed setting. On the sexual side, apomixy is a typical field of tropical grass research for instance. Deeper investigation is necessary in the asexual reproduction of plants than in the case of temperate plants. On the vegetative side, dry matter accumulation of which authors (Zalensky 1954, Thomas 1965) have said that tropical countries are the fittest in many respects must be a favourite objective in our breeding policy.

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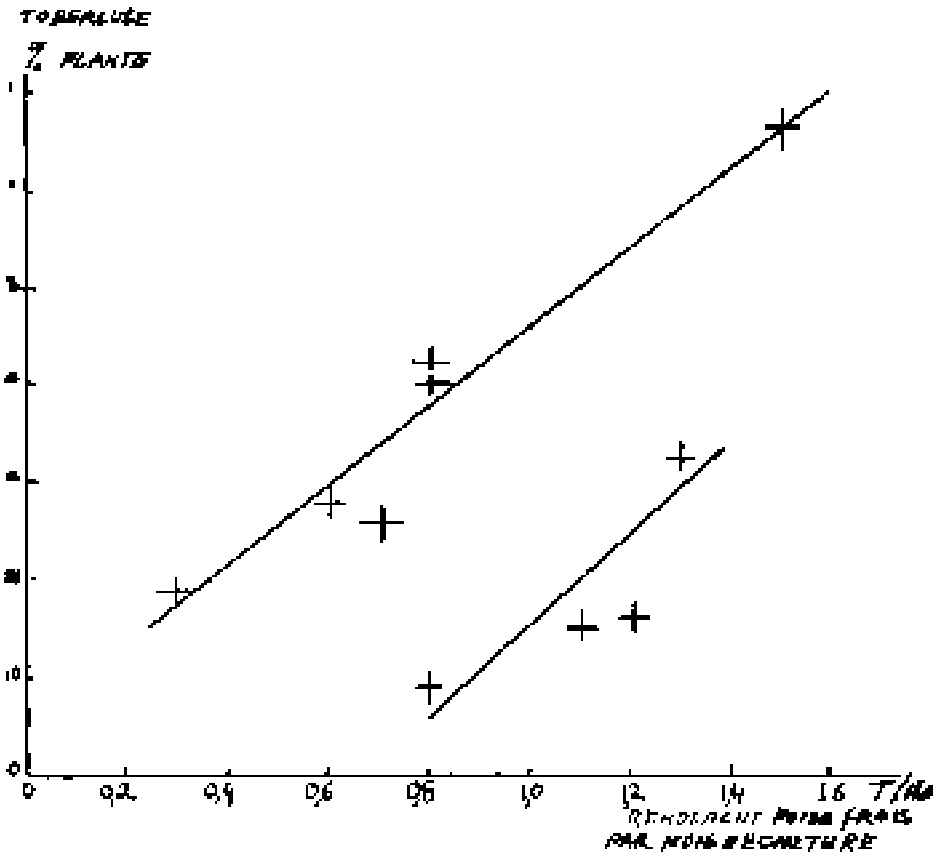
4

TUBERISATION ET RENDEMENT CHEZ
DIX VARIETES DE PATATE



DISCUSSIONS

Mr. I. Shrvm:

I would like to ask Mr. Haynes the details of the method used to induce sprouting with 2-chloro-ethanol and about the effect this had on survival of plant and on uniformity of sprouting ?

Mr. P. Haynes:

The planting piece is immersed into a solution of 2-chloro-ethanol in water. The concentration varies with the maturity of the yam. Since sprouting in yams is related to level of glutathione and so sprouting can be induced by weaker concentrations in older yams. After dipping in the solution the tubers are placed in a closed container for 24 hours. They are then placed in a sprouting bed, and kept moist and allowed to germinate. The normal polarity in germination of yam pieces where the head ends germinate before the tail pieces remains unaffected by 2-chloro-ethanol.

Mr. L. Edwards:

Commented on the affect of nitrogen applications to staked yams. He claimed that in experiments in Nevis in areas of high rainfall applications of nitrogen produced yields of up to 11 tons/acre on staked plots compared with yields of less than 9 tons on unstaked plots. The effect was reversed in low rainfall areas.

Mr. D. B. Williams:

On the question of the relative efficiencies of sweet and 'Irish' potato I would like to dispose of a possible aspersion cast on the quality of the sweet potato cultivars bred at St. Augustine. The U.S.D.A. miscellaneous Publication No. 572 reported that the Sweet Potato possesses 1½ times more carbohydrates than the 'Irish' potato. This advantage was maintained when calorific value was the index employed in this assessment.

Since this comparison involved the high carotene sweet potato and not a starch variety which is more like those bred locally, then I think that the suggestion of greater efficiency for the Irish potato would seem to me to be untenable.

Mr. P. Haynes:

I will agree with Mr. Williams that weight for weight the sweet potato is superior in carbohydrate content to the 'Irish' potato. However we must compare like things. My comparison was based on production per acre per year. The sweet potato occupies the land for a longer time than the 'Irish' potato when grown in the tropics. On a theoretical basis there would be a greater production from the 'Irish' potato per unit time. The contention I hold will still stand.

Professor F. L. Milthorpe:

Mr. Chairman if Mr. Haynes and his colleagues would forgive me saying so, I think that this work does show excellently the way we must follow. It is an example which many of us must follow in order to understand the way in which tropical crops are behaving, and how they increase yield. Also it does illustrate a point which we tried to make elsewhere (in the study group) and that is that the yield of many of the crops is likely to be increased, if one selects for a much higher ratio of tubers to leaf area and then puts on a lot of nitrogen. I think this is exactly what Mr. Haynes has shown in the comparison of the two varieties of sweet potato.

I understand that this is the basis of increases in yield in cereals for the last 20-25 years. Mr. Haynes' work seems to suggest that the same type of phenomenon operates with the tuber crops as with the grain crops.

Dr. L. A. Wilson:

Mr. Haynes mentioned a decrease in concentration of glutathione. Is there a suggestion that ethylene-cholorohydrin (2-chloro-ethanol) helps to decrease this concentration and therefore inhibits sprouting ?

Mr. P. Haynes:

2-chloro-ethanol causes an increase in concentration of glutathione and this allows germination to take place.

Dr. G. Samuels:

You mentioned t1/pt and that you considered this a negative factor in yielding ability. You cannot use the same ranking order as for the other factors which were positive

Dr. L. Degras:

Yes, I have used an inverse order.

Mr. E. G. Gooding:

In table 1, a set of figures are put down for the dry matter yield in kilograms per hectare per day for yams and sweet potatoes. Now this, I think, is related to the full crop duration. I just want to make the comment, in passing, that if you consider the period of bulking of the yam tuber, this takes place in roughly ten or eleven weeks, in other words, 70-80 days, the rate of bulking is extremely high. We found this in observations in commercial fields. This works out to something like 80 kilograms per hectare per day, which is about twice as high as the figures given here.

Dr. W. O. Jones:

I am very diffident about asking this question of Mr. Haynes, but this is supposed to be an inter disciplinary as well as cross cultural international conference, so I would like to ask your indulgence for a minute. I have tried to understand that chart on the board, about the C9 and O49 sweet potatoes. It seems to say — and this is all it says to me — that if you want to put 120 lbs of nitrogen on per acre you may do so, and it will not reduce your yields, or what you get without the nitrogen, if you just wait a little longer for it.

Now, does it say any more than that ? And if that is what it says, is not the conclusion 'let's not put the nitrogen on unless we are producing nitrogen at a negative cost'. Or have I got it all mixed up ?

Mr. P. Haynes:

Yes, I agree. Your assessment is quite correct. But we are using this to explore variety response, and we want to find out a principle here. There is the possibility that there are other varieties, which will give this response earlier, and these are what we must look for. We should not think only in terms of response to nitrogen because this response is complex and varies between varieties.

The charts show something of that varietal difference. This work is explorative and is designed to gain a better understanding of the nature of response rather than to formulate fertilizer practice. The particular varieties were chosen because of their contrast in leaf habit.

Dr. G. Smith:

I feel even more diffident about speaking to a gathering of plant physiologists and all the other "ologists" because I am a physicist, but it always strikes me, as being of the utmost importance, in experiments such as we have heard about this morning, to know, not only what varieties you have got, what fertilizer you have got, whether you stake or you don't stake. What has happened to the weather ? Are weather factors always directly comparable in your experiment ? How do these vary ? Once we can mention the question of quite different answers in low and high rainfall areas in, I think it was Nevis. What has happened in your various experiments with the soil moisture ? Are they always comparable ? Will you get the same answer next year when it is very dry or very wet ?

Mr. P. Haynes:

Thank you very much Dr Smith. I am glad that you raised this point. We are aware of these differences, and in fact, our trials are conducted in the dry season and in the wet season and we get different responses. One finds, a very much lower leaf area development in the dry season and an earlier production of tubers. We are also examining the growth period, in terms of radiant energy, and for this, we are going to depend very heavily on you to supply us with some data, we will be taxing you in a very short time, so I am very glad that you are showing this interest.

Dr. L. A. Wilson:

I wonder if I could put a question to both Mr. Haynes and Dr. Degras. In Dr. Degras' work on sweet potato, I think he considered the ratio of tuber weight to total dry matter. Am I right ?

Dr L. Degras:

Yes.

Dr. L. A. Wilson:

Now I would like to ask you how you interpret the results of this ratio, and what are your considerations with respect to the results of C9 and O48.

Dr. L. Degras:

I think it is very difficult for me to give you an answer about that. My observations on different varieties, and it seems too, that I cannot now make an indication on another way of conditions. I don't know very well.

Chairman:

Mr Haynes, would you like to comment ?

Mr. P. Haynes:

I will ask Dr. Spence to answer this one.

Dr. J. A. Spence:

Certainly the analysis has to continue into the tuber dry weight in relation to total dry weight. The leaf area produced affects this ratio, and the assessment of final yield and how leaf area affects final yield must be made in relation to this ratio. However, I would not at this stage interprete the results of this ratio for C9 and O48

Mr. E. C. Pilgrim:

We have just been discussing one point, in connection with the chart on the board. Might not the response of O48 be somewhat modified by the fact that C9 is a four-month variety whereas O48 takes six months to mature ? Might not the response have been greater if the graph had been extended for another 2 months.

Mr. P. Haynes:

Well unfortunately it was not extended for another 2 months. But I do not know that we can claim that the C9 is going to continue to increase. That phase of the curve is too indecisive for us to make a definite statement as to the trend that it would continue along, for this period of time.

The other thing, which we have to consider — is that total tuber dry matter does not necessarily indicate marketable yield of tubers. When grown for these long periods, tuber size is becoming rather large, and deformities in tubers begin to appear. This adds a further complication. We still make the contention that this work is aimed at exploring the system rather than making recommendations on practice.

Dr. B. N. Cash:

Now, I am an Agricultural Engineer, and the only reason that I dare speak at this moment is because of the lead given by our Physicist friend, when he mentioned climatic conditions. Sometime ago, we were involved in doing some drying work in East Africa, and it was of importance to know the climatic conditions. We made a comparative study of only one factor, sunshine, over which we have very little control, and we observed values from data from about 8 to 10 stations located within 5 to 6 miles of each other, in a high altitude mountainous area, in two different areas of East Africa, and in both cases we found that the sunshine values obtained at one place bore hardly any relation to another place 3 or 4 miles away. In both instances differences in the average sunshine over a month, taken for a period of 6 to 8 years showed that at the stations the values can be high, or as low by 1½ hours per day. And I simply quote this figure to emphasise how important it is to observe other factors that contribute towards plant growth.

Mr. James:

In describing the yield increases which have been obtained from various trials, or comparing different qualities, I am wondering whether it is not possible to indicate what has contributed to that increase in yield. Whether it is size of tuber or number of tubers, particularly for a crop like sweet potato, in which size is very important as far as commercial suitability is concerned.

Mr. P. Haynes:

In most of these yield increases it has been on the basis of size of tuber increases. There is a small contribution to yield from number of tubers, but usually we find that, with an increased number of tubers their size is smaller, and therefore, this does not usually reflect an increase in marketable yield.

IRRIGATION TO INCREASE SWEET POTATO PRODUCTION

— by —

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Irrigation to supplement rainfall is necessary in most years to obtain best yields of horticultural crops. If adequate soil moisture to meet the needs of sweet potatoes or other crops is not provided, many of the recommended practices, such as better seed selection, use of improved varieties, proper fertilization and others are of little economical advantage.

The value of irrigation water to increase sweet potato yields has been reported by several research workers Hernandez *et al* (1956) and (1965) Jones (1961), Lambeth (1956), Peterson (1961), Ware and Johnson (1958).

Irrigation studies were conducted on a Richland silt loam soil at the Sweet Potato Research Center, Chase, Louisiana for several years to determine the effects of supplemental irrigation on sweet potato production.

MATERIALS AND METHODS

The irrigation water to the test plots was applied either as a furrow application or with a sprinkler system. The Richland silt loam soil used had an infiltration rate of 0.5 inch of water per hour. The sprinkler system was designed to irrigate 40 acres in a 10-day period when irrigating 10 hours per day, and applying 2.5 inches of water for each setting of 2 acres. A total of 720 feet of lateral 4-inch lines with 36 sprinkler nozzles was needed to cover 2 acres. Each nozzle delivered 12.5 gallons per minute and the nozzles were spaced 40 feet x 60 feet apart. There were 700 feet of 5-inch main water line. Part of this system or furrow irrigation was used to irrigate the experimental plots.

The physical analysis of this silt loam soil showed that the field capacity was 19.5 percent on an oven-dry weight basis and the wilting point was 6.5 percent. Since the water held in the soil between the field capacity and the wilting point is available to the plant, this is usually called "available water". In this case the available water amounted to 13.0 percent.

In these experiments the soil moisture samples were obtained in the topsoil, the upper 10-inch layer of soil, and in the subsoil, the 10 to 18-inch layer of soil. The soil moisture on all of the samples was determined in duplicate on an oven-dry weight basis.

The temperature and relative humidity were continuously recorded on a hygrothermograph.

Four sweet potato varieties were used over a 6-year period. Randomized block experimental design was used in 1953-56. A rate of 600 pounds of 6-12-6 per acre was used in all experiments.

In 1964 and 1965 a split plot design was used to study levels of soil moisture x rate of nitrogen. The irrigation levels were as follows: check (natural rainfall); soil above 25 percent moisture; and soil above 50 percent moisture. The main plots were irrigated treatments and nitrogen levels of 0, 30, 60 and 90 pounds per acre were the sub-plots. Sixty pounds of each P_2O_5 and K_2O were applied to all plots.

Rainfall in inches at Chase in 1964 was as follows: June 1.49; July 3.80; August 3.03; September 3.84 and October 1.00. In 1965 rainfall in inches was as follows: June 1.15; July 0.86; August 3.86 and September 6.59. *Centennial* variety was used in 1964 and 1965.

RESULTS AND DISCUSSION

The 4-year monthly rainfall for the major portion of each growing season at Chase and for each year at Winnsboro (5 miles north of Chase) is shown in Table 1. The rainfall shown for Chase was recorded approximately 1/16 mile from the test plots.

Table 1. Rainfall in inches for 4 years (1950 through 1956)

	1953		1954		1955		1956	
Month	Chase	Winns-boro	Chase	Winns-boro	Chase	Winns-boro	Chase	Winns-boro
Jan.		3.94		4.96		5.65		2.21
Feb.		6.82		1.94		7.27		10.57
March	—	7.01	—	3.14	—	2.27		4.57
April	7.00	6.69	9.65	4.02	6.40	6.36	4.09	4.66
May	15.00	16.38	6.85	10.04	7.26	8.59	4.19	3.88
June	0.00	0.63	0.72	1.83	3.76	9.81	2.42	1.94
July	2.50	2.18	1.30	4.67	6.38	9.80	3.24	2.86
Aug.	1.80	1.06	0.90	1.26	1.62	1.90	5.00	5.83
Sept.	0.60	0.73	1.55	1.81	2.86	2.06	1.08	0.79
Oct.	0.92	0.92	1.61	1.61	1.00	1.00	1.86	1.93
Nov.		1.67		1.51		4.53		1.96
Dec.		8.38		2.89		2.80		9.24
Annual Rainfall	—	56.41	—	39.68		62.34		50.44

There was unequal distribution of rain within and between years. The months showing the lowest average rainfall were June, August, September, and October. Rainfall in general was highest in the early part of the growing season when water requirement of the plants was lowest.

Two irrigation tests were conducted in 1953. *Earlyport* variety was used in the first test and *Goldrush* and *Earlyport* in the second.

There was an unusually large amount of rainfall in 1953 in May; none in June; and little in August through October (Table 1).

The first test was watered with approximately 1.5 inches of water per irrigation on June 17, July 7 and August 3. At the period that *Earlyport* was beginning to set storage roots, the soil in the non-irrigated plots was very low in moisture. There were practically no roots set in the non-irrigated plots, while in the irrigated plots there was a good set of sweet potato roots. The irrigated plots produced 234 bushels of marketable sweet potatoes per acre as compared with 10 bushels per acre for the non-irrigated plots (Table 2). There was an increase in yield of 49.8 bushels for each acre-inch of irrigation water applied in this early test.

In the second test using *Goldrush* variety, the irrigated plots produced 146 bushels per acre as compared with 80 bushels for the non-irrigated plots. The irrigated plots received approximately 1½ inches of water per irrigation on July 3 and 10, and on August 7 and 17. *Earlyport* produced 158.1 bushels per acre on the irrigated plots as compared with 95.8 bushels on the non-irrigated plots. It produced an average increase in yield of 10.4 bushels for each acre-inch of water applied.

In 1954 two irrigation tests were conducted. All of the plots had the same soil moisture content at planting time. The first irrigation was given on June 17.

As shown in Table 1, the rainfall at Chase was low in June, July, August, September and October, 1964. In the non-irrigated plots the soil moisture dropped below 20 percent available moisture and by July 20 it had declined to 5 percent, and it remained below that for most of the season. The irrigated plots were given six irrigations using 1.5 to 2 inches of water per irrigation. In the irrigated plots the soil remained above 30 percent available water and rose to approximately 82 to 100 percent available moisture immediately after each irrigation. The irrigated plots produced 386.0 bushels of sweet potatoes per acre as compared with 70.2 bushels on the non-irrigated plots (Table 2). There was an increase in yield of 28.7 bushels for each acre-inch of irrigation water applied in this test.

In the second test with *Goldrush* in 1964, the irrigated plots produced 274.9 bushels of marketable roots compared with 110.2 bushels for the non-irrigated plots (Table 2).

Table 2. Effects of Irrigation on the Yield of Sweet Potatoes

Variety	Planted	Harvested	Irrigated	Non-Irrigated	Irri/Non-Irri.
Earlyport	4/23/53	8/24/53	234.0	10.0	224.0
Goldrush	6/18/53	8/ 8/53	146.0	80.0	66.0
Earlyport	6/18/53	8/ 8/53	158.1	95.8	62.3
Goldrush	5/27/54	9/21/54	386.0	70.2	315.8
Goldrush	6/18/54	10/8/54	274.9	110.2	164.7
Goldrush	6/ 6/55	10/18/55	345.6	283.5	62.1
Unit I. P. R.	5/ 7/56	10/14/56	359.0	175.6	183.4
		Average	271.9	117.9	154.0*

**Significant at .01 percent level.*

In 1955 there were frequent rains from June through the middle of August. The soil moisture for this period remained mostly above 50 percent available.

However, little rain fell in late August, September and October, and topsoil dropped below 12 percent available moisture after mid-August and declined sharply thereafter. The irrigated plots were watered on August 19 and September 8 with approximately 1.5 inches per irrigation. The irrigated plots produced 345.6 bushels of marketable sweet potatoes per acre compared with 293.5 bushels for the non-irrigated plots.

In 1956 there were frequent light showers throughout the growing season which caused sharp rises in soil moisture; however, the effects of these light rains were of short duration. There was low rainfall in June and July and especially in September and October (Table 1). The irrigated plots were watered four times. The irrigated plots produced 359.0 bushels per acre compared with 175.6 bushels for the non-irrigated plots. There was an increase of 17.5 bushels per acre-inch of irrigation water used.

The yield data for the different soil moisture levels are shown for 1964 in Table 3 and for 1965 in Table 4.

Table 3. Effect of Different Soil Moisture Levels on Yield in bushels per acre of Sweet Potatoes in 1964

Treatment	U.S. No. 1	U.S. No. 2	Culls	Jumbos	Total
Check (Natural Rainfall)	196	60	12	18	286
Above 25% Moisture	205	72	15	33	325
Above 50% Moisture	234	88	16	62	400
lsd @ .05	ns	ns	ns	31	71

Table 4. Effect of Different Soil Moisture Levels on Yield in bushels per acre of Sweet Potatoes in 1965

Treatment	U.S. No. 1	U.S. No. 2	Culls	Total
Check (Natural Rainfall)	174	81	22	277
Above 25% Moisture	248	79	26	353
Above 50% Moisture	250	106	33	389
lsd @ .05	70	ns	ns	86

As shown in Tables 3 and 4, the yields from irrigation treatments were significantly higher for total yield in 1964 and for yield of U.S. No. 1 roots and total in 1965.

The data for levels of nitrogen are shown in Tables 5 and 6.

Table 5. Effect of Different Nitrogen Levels on Yield in bushels per acre of Sweet Potatoes in 1964

Treatment Lbs. per Acre	U.S. No. 1	U.S. No. 2	Culls	Jumbos	Total
0 Nitrogen	247	85	14	30	376
30 Nitrogen	209	76	15	51	350
60 Nitrogen	224	76	13	40	353
90 Nitrogen	167	56	15	30	268
lsd @ .05	57	25	ns	ns	71

Table 6. Effect of Different Nitrogen Levels on Yield in bushels per acre of Sweet Potatoes in 1965

Treatment Lbs. per Acre	U.S. No. 1	U.S. No. 2	Culls	Total
0 Nitrogen	259	112	26	397
30 Nitrogen	248	86	25	359
60 Nitrogen	210	78	27	315
90 Nitrogen	178	78	30	286
lsd @ .05	58	ns	ns	72

The silt loam soil used showed no response to levels of nitrogen.

SUMMARY

The water requirement for high fleshy root production varied during any growing season. Usually sweet potato transplants have little or no feed (or fibrous) roots at the time of planting. If the soil contains available soil moisture with soil temperature above 70°F in the top soil where the feed roots develop first, the root system grows rapidly, whereas, if the soil moisture is very low, the roots develop poorly.

Sweet potatoes required an average of 0.10 acre-inch per day in the early part of the growing season. This gradually increased to as much as 0.25 acre-inch of water in midsummer, depending on stage of plant growth, temperature, humidity, wind, and other environmental factors

High soil moisture levels over a period of several days, 40 to 50 days after transplanting — especially with good fertility, can cause sweet potato plants to become excessively vegetative at the expense of storage root formation and growth.

Drought approximately 40 days after transplanting of sweet potatoes, allowing the soil to drop much below 20 percent available moisture for a few weeks before fleshy root set, caused great reduction in yield. Also droughts in the latter part of the growing season will slow down fleshy root growth and reduce yields of marketable roots

The use of irrigation water in 1953-1956 produced an average increase of 154 bushels of marketable sweet potato roots per acre or an increase of approximately 23 bushels for each acre-inch of irrigation water used.

Supplemental irrigation significantly increased sweet potato yields in 1964 and 1965. However, there was no response of sweet potato to nitrogen levels used.

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DISCUSSIONS

Dr. Rogers :

First of all, what soil types were used in your plots? Then what are the treatments for giving these other than the irrigation and the fertilizers? Were there any rotations for example? What were the effects on the soil? Was there any increment in the disease populations, after irrigation?

Dr. Hernandez :

First let me say that soil type was a silt loam soil which is the best soil for sweet potato production in our state. In regard to our soil rotation system, normally we grow sweet potatoes in one year and then grow soya bean for two years and come back to sweet potato when we harvest the beans. As far as the effects on the soil are concerned, we have a rotation test that has been in existence for over 8 years, whereby we have maintained a certain type of rotation. One treatment includes sweet potatoes every year and I can tell you that up to date we are producing comparable yields to those we were producing in the first year sweet potatoes were grown on that plot. We use clean seeds at all times, and we have had no disease problems or insect problems on these particular plots. When we harvest our sweet potato roots we turn the vines into the soil. We have been able to maintain our soil productivity throughout the years using recommended rates of fertilizer 8 - 12 - 8 per hundred pounds. Dr. Martin will cover the disease and I would like to defer that problem until he comes.

Prof. Milthorpe :

I'm very interested in these results because these are exactly the same type of response as one finds with the Irish potato, particularly the lower soil moisture and initiation of tubers. I think I may differ a little from you in the interpretation of the mechanism involved. I think there is some evidence which would suggest that the shortage of water leads first to a direct effect on rate of cell division and there is a slowing down on the rate of foliage growth which leads to earlier initiation rather than the direct effect on respiration. The question I really want to ask is what happens with soil moisture deficit later in the season? Do you get any type of response akin to the second growth that one finds in the Irish potato? In other words, do the root tubers stop growing and then with restoration of the water supply start up again, leading to mal-formed tubers?

Dr. Hernandez :

Yes, that can become a very serious problem. If you go into a very severe soil moisture depression stage you arrest growth, subsequently when soil moisture becomes adequate and growth is resumed, in many cases the roots crack. This is a genetic character and we screen rigidly to eliminate cracking. Some seedlings will split all over when that condition is permitted, others will resist the conditions quite well, but there is a tremendous varietal variation.

Professor Steppler :

I would just like to interject for a moment, and ask a question myself, if I may. Water is a limiting factor in many areas and I would like to put two questions to Professor Hernandez. What about the quality of the water on the potato? Can they stand brackish water? And secondly, what is the efficiency of water usage. What is the pounds of water per pound of roots on the irrigated versus the non-irrigated if we are looking at an area where the water is truck supplied?

Dr. Hernandez :

As to the quality of the water, we have a very good experience to relate because at one place where we have a sweet potato station our irrigation water came out with a salinity content of three thousand parts per million, and of course that is prohibitively high. However, we were able to dilute it down to about fifteen hundred parts per million using other levels of water. We used this quality water in 1954 with very good results. About a quarter of the roots were somewhat impaired. But sweet potatoes can tolerate saline levels say from 600 up to 1000 p. p. m. As to the efficiency of water usage, I would say that the sweet potato can use water very efficiently. Now there are several things to consider. Remember I said that this soil will absorb a half inch of water per water and that's a fairly good water absorption rate. Now many of the soils will absorb much less water, some much more. Now this soil had what we call a 'plough sole' at a depth of roughly 12 to 15 inches, which is impervious and I might add to what I said earlier, that in the plots that we irrigated, feed root systems penetrated very deeply through that 'plough sole' or pan area. However, where we didn't irrigate, our roots concentrated on the plough or on the pan area and were something anywhere from a ¼ to a ½ inch thick of matted fibrous root system. I cannot give exact figures but the increase in yield per acre inch was quite satisfactory.

Mr. Gooding .

I notice you said that if the soil contains available soil moisture the root system grows rapidly, whereas if the soil moisture is very low the roots develop poorly.

I was interested to see this observation as it ties in with observations we have made in Barbados. We had no way of controlling soil moisture and we tried to correlate yield with rainfall, with crazy results. We then took into account measurements of the rate of evaporation of moisture from the soil made by one of my colleagues who had shown that in parts of the Island the evaporation rate from bare soil amounted to 0.2 inches per day. Rather arbitrarily, we reckoned that to be really effective the rainfall on any one day would have to exceed 0.2 inches. When we compared the number of inches of 'effective rainfall' that is the excess of rainfall over 0.2 inches per day, with ultimate yield we found a strong correlation between the figures for the first month and the production of tubers. Further we found that the effect of this 'effective rainfall' was mainly on the establishment of the young plants, and in areas where the effective rainfall figure for the first month was in the region of four inches we had final stands of 4,800 plants/acre (almost 100% survival), but where the effective rainfall was in the region of one inch during the first month the stands amounted to only about 2,800 lbs/acre, and the ultimate yields were more or less proportional to the survival of the plants.

ROOT CROPS IN GHANA

—*by*—

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Cassava, (*Manihot esculenta*, Crantz.) Yams, (*Dioscorea* spp.) Cocoyams, (*Xanthosoma sagittifolium*, Schott., and *Colocasia antiquorum*, Schott.) and Sweet potatoes (*Ipomoea batatas, Poir*) provide the main source of carbohydrates to a large proportion of the population of the tropics, especially the inhabitants of the wetter tropics, including Ghana. When cereals are in short supply, as they occasionally are, these root crops supply the sole source of carbohydrates.

Generally, they are not grown on a large scale. Nevertheless, they are of immense importance, and in every garden or small holding throughout the tropics one or more of these crops are grown. The total annual production must therefore be considerable.

These crops are as important as the Irish potato is to the European as constituents of the daily diet. They can be grown on a variety of soils and as a rule, require or receive little attention. They are therefore relatively cheap to produce, but they yield very heavily. Cassava may yield up to 12 tons or more per acre, Yams, about 5 tons or more, Cocoyams about 5 tons or more and Sweet potatoes about 6 tons or more on peasant farms. All these crops could certainly yield much more with better management and the planting of proven varieties. At the moment, perhaps with the exception of cassava and yams, varieties do not generally play any major role in the cultivation of these root crops in Ghana.

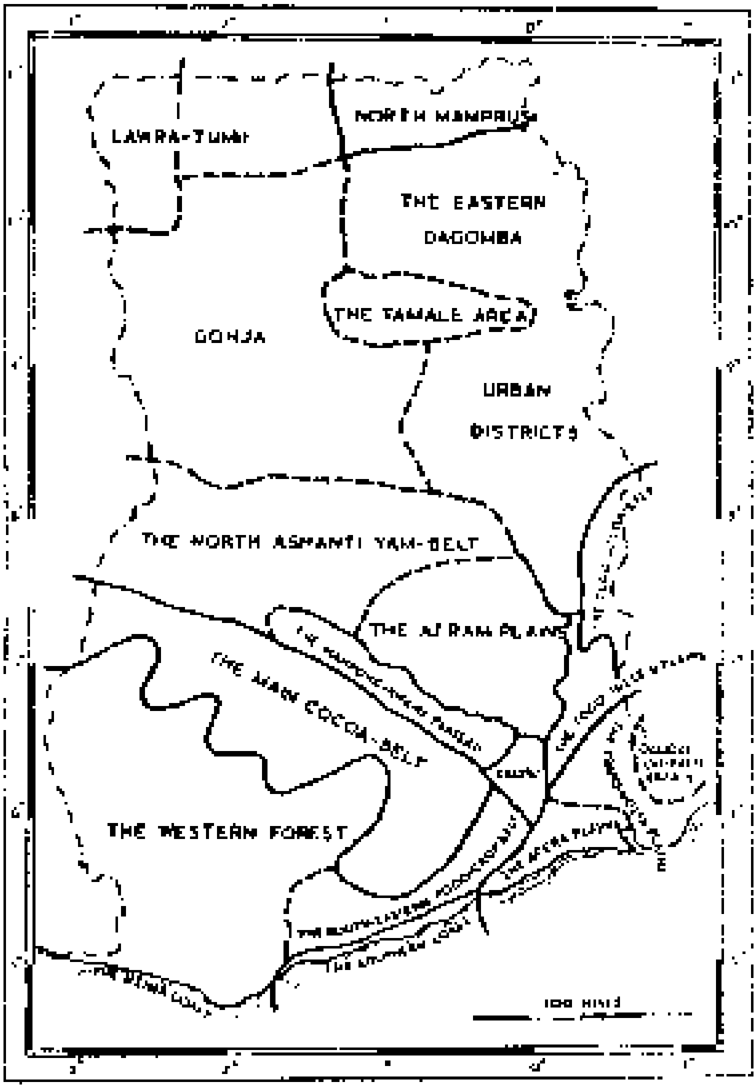
In contrast with these tropical root crops, to obtain high yields (about 10 tons per acre) with Irish potatoes (which have been and are still being grown in Ghana) under temperate climatic conditions, a very high level of soil fertility ensured by heavy manuring is required in addition to frequent cultivations to check competition by weeds

While diseases do not generally appear to be a major problem in the cultivation of the tropical root crops, they are the major problem with the cultivation of Irish potatoes everywhere in the world, be it in the temperate regions or at high or low altitudes in the tropics.

Many disease of the Irish potato are well known because intensive research has unearthed these diseases together with their control measures. On the other hand, diseases of tropical root crops appear to be of minor importance, probably because the depth and scope of researches on these crops in the tropics do not come anywhere near to what has been done on the Irish potato in temperate regions. The havoc done by disease to tropical root crops is therefore not really known and would appear at the present, at least, that the growing of Irish potatoes is a more specialised and expensive business than the growing of any of our tropical root crops.

Of course, yams, and sweet potatoes have their storage and sprouting problems but so also has the Irish potato. Cassava has its virus diseases, Mosaic

GHANA: PROVISIONAL AGRICULTURAL REGIONS



FROM White, H.P. Provisional Agricultural Regions of Ghana
Journal of Tropical Geography, Vol. 11, 1958.

and Streak, (the latter not present in Ghana) and Cocoyams their root rot, but these would appear to do less havoc when compared with the havoc done to the Irish potato by Late Blight, Wart, Potato viruses X and Y, to mention only a few diseases.

ROOT CROPS IN GHANAIAN AGRICULTURE

The importance of Cassava, Yams, and Cocoyams in terms of their distribution, acreages and total annual production would be seen by glancing through Tables 1 and 2, respectively. Sweet potatoes do not appear in the tables because they are unimportant. (Wills 1962).

Cassava:

Cassava used to be grown only in Southern Ghana, particularly, the non-forested areas which still produce about 50% of the total crop. The crop is now being increasingly cultivated in the forested and savanna areas in other parts of the country also. Even as far north as Tamale, one often sees cassava growing in small gardens here and there.

It is generally the last crop to be planted in rotation when the land is left to fallow. This, however, is not the general practice, and may be confined only to areas where the rainfall is adequate and more reliable, thereby making it possible for good crops of maize to be taken.

In the drier eastern part of the coastal plains where comparatively little maize is grown, one often sees crop after crop of cassava being grown on the same piece of land year after year, generally but not always, in mixed culture with legumes, i.e., groundnut (*Arachis hypogea*.) bambara nuts (*Voandzeia subterranea*) and cowpeas, (*Vigna unguiculata*) and occasionally with vegetables—tomatoes, peppers, okroes and garden eggs

Yams:

The yam is a crop of the savanna area where it grows well and gives good yields (Torto 1956). Its cultivation is centred around Northern Ashanti, Brong Ahafo, Krachi and along the main roads leading to Wa, Tamale and Yendi in the North. Unlike cassava, great care is exercised in the choice of fertile land for yam growing. According to Torto (1956) land rested for about 6 years is known to produce tubers of good size, whereas lands cultivated more frequently yield poorly. New uncultivated lands in the savanna are very extensive and growers continue to open up more land for planting. The crop is usually interplanted with various crops, i.e., cowpeas, upland rice, vegetables, etc.

D. rotundata and *D. alata* are also produced in the forest areas and even as far south as the Coastal Scrub and Thicket zone, the latter area being where they were first encountered and described by the early European traders and explorers. Production in these areas, however, seem to have declined considerably. Farms here are smaller and fewer ; mounds and yields are also smaller than those of the savanna areas.

Though the types of crops being grown in the Northern (Interior) savanna areas were not known at the time the early European explorers were describing those being cultivated on the Coastal areas, it would appear that the yam has moved northwards where it found a more favourable environment than the south. Only a few areas (Kpandu, Asesewa, Bawjiase and Mankessim) are left in the forest zone where *D. rotundata* is cultivated on a commercial scale. Around Akim Oda where some yams are also grown, the quality is poor and are only occasionally offered for sale. According to Tono (1956) the climate of the forest areas is too humid, and the soils unsuitable for yams. There is also not a well organized system of seed supply as in the savanna areas where some farmers specialize in seed yam production on a commercial scale.

Cocoyams :

Both *Colocasia* and *Xanthosoma* cocoyams are cultivated throughout the forest zone. There are four varieties of the former, and one of the latter (Wright 1930b).

In the past, Cocoyams were planted almost everywhere after clearing virgin forest for farming. Today, whenever a piece of secondary forest is cleared, cocoyams spring up all over the cleared area, these plants having arisen from old pieces of tubers which for years had been lying dormant in the soil after the old farm had been abandoned and the forest had rejuvenated. It is not known how long such tubers remain viable, but Wright (1930b) cites an interesting example in the Aburi gardens when in 1930 part of a Funtumia plot was cleared after 34 years of growth and within a month cocoyams sprung all over the cleared area. Presumably cocoyams had been growing on the site before the Funtumia was established but due to shading, weed and root competition, etc., they had apparently died out. Over these three decades, however, some of the tubers had retained their viability and had sprouted when suitable conditions for growth were created. These tubers produced healthy plants.

In the cultivation of cocoyams, these plants which spring up on clearing secondary forest are thinned out when growing too thickly in places, and gaps filled by pieces of seed consisting of portions containing buds of the old rhizome. When mixed cropping is practised, which is the usual practice, gaps are not filled with seed cocoyams after thinning, but with other crops such as maize, plantains, beans, etc.

When the mature crop is dug up and the cormels of a plant removed, the central corm is trimmed down and the remaining stump planted in the same soil, if not at the same spot, from which the plant has just been harvested, or it is covered with soil to serve as a seed for the next generation.

The cormels which this seed produces are smaller than those of the previous generation, and vary in shape, being from round to oval, instead of flask shaped. These are harvested in a similar manner ; the old stumps being trimmed again to serve as seed.

This process may go on generation after generation till such time that yields and quality of the crop so deteriorate that the farmer gives up the farm for another, and the entire process starts again in the new farm. Meanwhile, the abandoned farm gradually becomes over-grown into secondary forest.

Sweet Potato:

Sweet potatoes are mainly grown in the interior and coastal savanna zones, and in other parts of the country, all on a small scale. It is not yet an important root crop compared with the others. There appears to be two main varieties with several gradations in between, (1) A white-tubered, (white fleshed) variety commonly cultivated in the coastal areas, and (2) A purple-violet-tubered, (white-fleshed) variety more common in the North.

Acreages and production of various crops, not excluding root crops, have increased tremendously since independence (1957), and though the figures in Tables 1 and 2 may not be correct now, there is reason to believe that compared with the other crops, the same percentages in terms of acreages and yields have been maintained.

Table 3 is compiled from a countrywide survey of the distribution of expenditure within the group "local foods". From it, it would be seen that the root crops together with their products account for *21.28%* of the expenditure on local foods (i.e. 15.82 + 5.46). All the cereals and their products taken together account for *17.00%* (i.e. 10.45 + 6.55%). Meat and Poultry account for *14.00* and Fish *18.53%*.

The importance of root crops in Ghanaian agriculture and in the Ghanaian diet cannot therefore be over-emphasised. More is spent on them than any other foodstuff. Cassava alone with its products account for 12.27% (6.81% + 5.46%), Yam 6.89%, Cocoyam 2.07% and Sweet Potato only 0.05%. The relative importance of the individual root crops is thus indicated.

ROOT CROP INVESTIGATIONS IN GHANA.

Despite their importance, and the fact that they have been cultivated in Ghana for a very long period, (the most recent introduction, *X. sagittifolium* having been cultivated for over a hundred years) with the exception of cassava and perhaps yams, these root crops have not and are not receiving the research attention they deserve.

Research into all these crops which was started round about 1930 by the then Department of Agriculture has not been kept going for all the crops. In fact, research work on sweet potatoes and cocoyams ceased as far back as the early 1930's and the early 1940's respectively, and has not since been revived. Active research on yams also ceased during the 1930's but has had to be revived recently (i.e. since 1958) primarily because of the great damage being done to the crop by the yam tuber beetle in the main growing areas. The work on cassava has been the least interrupted. Except for a 6-year break from 1948 to 1954, it is still being continued.

Sweet Potato :

The only investigations on Sweet potatoes in Ghana on record were the testing of introduced varieties at Kpeve Station (Anon 1931) and (Anon 1933) in 1931 and 1932. The mean yields of these introduced varieties over a period of two years are given below :—

(1) Six weeks	5,174	lbs/acre	(6) Red Vine	1,800	lbs/acre
(2) Brook's Seedling	3,995	,,	(7) Palime	1,737	,,
(3) Trinidadian	3,070	,,	(8) White Sealy	1,637	,,
(4) Jackson	2,840	,,	(9) Brook's Gem	1,576	,,
(5) Caroline Lee	2,521	,,	(10) Red Nut	1,151	,,

palatability tests found Red Nut and Brook's Gem, the poorest yielders, to be among the best in flavour.

More varieties were introduced to Aburi Gardens in about 1933 from the New South Wales, Australia (6). These were (1) Wannop, (2) Puerto Rico, (3) Pierson, (4) Nancy Hall, (5) Yellow Strasburg, (6) Southern Queen, (7) Ashburn, (8) Vineless and (9) Triumph. No record of their performance is available.

It is not clear what happened to these introductions. It is not on record whether or not the best varieties among them were maintained and given out to farmers, though it is likely this might have been done. However, with the passing of time, they have all become mixed and disappeared together with any useful information that might have been accumulated about them. The present position is that though many varieties of sweet potatoes are grown on a small scale in the country, their names, yields and other qualities are not widely known. Farmers grow what they like or what they can get hold of. It would however appear that a variety whose tubers have a white skin and a white flesh, said to be of "local" origin, is the most popular and most widely grown around the coastal areas, and another, with purple or violet skin and white flesh is the most popular and widely cultivated in the Northern and Upper Regions.

Clerk (1961) observed virus-like symptoms on Sweet potatoes in the Akim Abuakwa district. This was later confirmed to be a virus disease and was named Vein Clearing Virus, after the nature of the symptoms.

It was said to superficially resemble a virus disease of Sweet potatoes found in parts of East Africa, Congo Leopoldville, and Ruanda Urundi. The vector in Ghana was found to be the Aleurodid fly *Bemisia tabaci* Genn.

The extent, distribution and damage to the crop has not yet been studied, probably because the crop is not so important at present. I would indeed be very surprising to some one from the West Indies or the Southern United States where so much sweet potatoes are cultivated and eaten in various forms that no research work whatsoever is being done on this crop, and that such a small amount is cultivated in Ghana.

Cocoyams.

Research work on cocoyams was mainly to find the causal organism and the control of a disease known as root rot. Wright (1930b) reported that the late stages of the disease was first observed at Wankye near Oda in 1925 by Dade, who in the absence of any other demonstrable organism capable of causing the disease, suspected nematodes to be the probable cause.

The disease takes the form of a wet root rot, wilting of leaves and the inability to form tubers, followed, in severe cases, by death and putrefaction of the entire plant. It may appear any time after planting. The sprouting "seed" may never push a shoot above the soil; plants may make an extremely stunted growth or may die off, after having become well established. In well established plants, symptoms are a flaccid appearance and yellowing of leaves. Chlorotic patches appear and often the leaves become attacked by leaf spotting fungi, e.g. *Cladosporium* colocasiae, *Phyllosticta colocasiae* and by woolly aphids and scale insects. Roots exhibit a dying back accompanied by a blackening necrosis and wet rot. Decaying corms are usually coated with a typical mycelial felt of *Sclerotium rolfsii*.

In 1926 Wright (1930b) found the early stages of the disease in other parts of the forest zone and after several investigations concluded that the disease was physiological, caused by a deficiency of Potassium and that all organisms found attacking the tubers were soil saprophytes and only became capable of attacking the roots when the plant was in a debilitated state. He recommended the following control measures :

(1) Cocoyams should be established on virgin soils not previously used for root crops.

(2) Bush should be burnt off and not only cut down and cleared away and the crop be liberally manured with all available wood ash.

(3) The health of the crop should be given a bit more attention by weeding more frequently, with a more thorough bush clearing since the crop likes sunshine.

(4) The practice of cropping till the soil became exhausted should be modified by reducing the number of times a crop was taken from the same farm.

(5) The custom of planting "seed" in exactly the same soil from which the previous crop had just been taken must be avoided as well as the use generation after generation of the same old stumps as "seed" since this practice was bound to result in seed degeneration.

This disease investigation work was followed up by Posnette (1945) who found inter alia, that :

(1) Application of wood ash did not reduce the incidence of the disease.

(2) Rogueing of all "wild" cocoyams immediately after bush clearing and then planting healthy setts delayed the onset of the disease so that a crop might be obtained.

(3) Once infected, plants might carry the disease and infect the soil.

(4) The disease might be carried by corms which had been surface sterilized and all roots removed.

(5) It might be transmitted by gently rubbing an extract of apparently healthy roots from diseased plants with carborundum powder on the roots of healthy plants.

(6) It might also be transmitted through leaf petioles grafted together.

He therefore suggested that for further investigation, the primary pathogen might be considered to be a virus which alone caused lesions on the roots and rendered the plant susceptible to a variety of weak parasites often present in the soil.

So far, as the author is aware this line of the work has not been followed up in Ghana since the publication of Posnette's paper. The economic importance of the disease itself is not very well known. It is not very likely that it has declined in its severity and is no longer of economic importance.

In his earlier work, Wright (1930b) showed that none of the then available cocoyams varieties was resistant to the disease. New introductions were therefore made in 1937 and 1938 from Hawaii, Sierra Leone, Nigeria, Trinidad, Puerto Rico, and the Panama Canal Zone. Almost all these introductions succumbed to the disease. However, one species *X. violaceum* var. Yautia Palma proved to be very resistant, but unfortunately it was not edible. Two other varieties, Conbiche and Morado proved more tolerant than the local types, but their tolerance was not sufficiently high to be of economic value.

Meanwhile, single plants of local varieties had sometimes been observed to stand unaffected while the rest of the farm succumbed to the disease. On the assumption that bud mutations were not uncommon in this species (since many varieties are known though true seed is rarely formed) Posnette (1945) carried out trials with 30 plants propagated from uninfected cormels and concluded that individual plant selection among local varieties had possibilities. This line of work also has not been followed as yet.

Posnette (1945) also investigated the possibility of producing true seed for hybridization purposes. When grown under light shade, he found that the local cocoyams flowered freely but none of the spathes set seed. A considerable amount of hand pollinations both of self and cross —was done without success. None of the introduced ones flowered.

While investigating the disease, Wright (1930b) also studied the local varieties. He found five different types of which four were varieties of *X. sagittifolium*, and one, a variety of *C. antiquorum*. All these he described some details.

The names of the sagittifolium varieties are given in Twi as :

(1) Amankani Pa or Amankani Kokoo—With purple petioles and pink tubers. The most common variety said to possess all the desirable cooking qualities of texture, taste, etc.

(2) Amankani Fufuo —Very similar to Amankani Pa, but with pale purple petioles and white tubers.

(3) Amankani Fita —Above ground parts resemble Amankani Fufuo, but the plant is smaller and more delicate. The tubers are white and the cormels have several constrictions.

(4) Amankani Antwibo — Petioles very pale green and cormels pink unconstricted. The central stem of this variety is edible.

The variety of *C. antiquorum* is known as Kokoo in Twi. Its peltate leaves are supported by pale green petioles. The tubers are white and smaller than the Amankani varieties. The central stem is edible. At one time this was the favourite variety, but is now seldom eaten except in cases of scarcity. Because it is very soft, it is preferred by old men and women, and on account of its poisonous properties, it has to be boiled for about 12 hours before it becomes edible as compared with the 20 minutes or so required for cooking the Amankani varieties. Also unlike the Amankani varieties, it is not suitable for fufu.

Yams.

Research work on yams started round about 1928 at Ejura Station, (de Graft 1960) with the collection and classification of cultivated varieties in Northern Ashanti and what is now Brong Ahafo and the Production of seed yams from elite varieties for distribution to farmers.

A very large collection, amounting to several hundred varieties was made and classified. About 80 *rotundata* and 133 *alata* varieties were classified. These varieties are still being maintained at Ejura station but with the passing of time some of them have disappeared. The remaining varieties in the collection were planted at Kwadaso, the main research station in 1961 so as to facilitate further observations on them.

Varietal and other trials involving mainly *rotundata* varieties were conducted on several Agricultural stations in the country about this time. The stations included Ejura, Wenchi, Tamale and Asuansi.

Variety Trials. In 1932, trials involving 15 local *rotundata* varieties were conducted at Ejura (Anon 1931c). The varieties were found to differ greatly as regards yield and taste. Yield ranged from 1½ tons to 4½ tons per acre. Pusadjo, Lilu and Zon the most commonly grown varieties, all yielded 4½ tons per acre. Brofo and Zagulamghe which were of the worst quality as regards taste, yielded 3 tons and 2 tons per acre, respectively, but both stored better. The best varieties in respect of taste, Asobayere and Larebako also yielded only 1½ tons and 2 tons per acre, respectively.

The other variety trial on record was conducted at Ausansi station (Anon 1936) involving 6 varieties. Yields which were given per set, (and not per acre) ranged from 7.95 lbs. to 6.80 lbs. The results were by no means conclusive since this was not a full scale trial, and plot size was small in addition to many gaps between plants.

Planting on mounds or planting on ridges. Trials were conducted at Wenchi and Ejura stations comparing the yields of yams planted on ridges with those planted in the traditional way, on mounds. (Anon 1933). Large disc ploughs were used to make ridges of similar size and spacing as the mounds.

Mounds or ridges at 6' apart were found to give the best yields.

The problem of staking becomes acute with mechanical cultivation. All trees are felled and stumped and stakes have to be provided whereas in the traditional way of clearing, farmers leave some live stakes in the form of unfelled trees. However, since the ridges are straight, an overhead line above the ridge supported only by a few stakes at intervals is all that would be required. The vines could then be trained on the line.

In these trials yields from ridges staked as described were as good, if not better, than those of farmers, and labour was considerably reduced. This method of planting yams on ridges is still being practised at Ejura and other agricultural

Staking Trials comparing staked and unstaked yams were conducted at Tamale (Anon 1931a) and Kumasi (Anon 1934).

Treatments ranged from no staking to stakes of 12' high. In both experiments overall yields as well as individual tuber size increased with height of stake: from 3,605 lbs/acre for no staking on Labaco at Tamale, to 10,568 lbs/acre—the average yields of 6 varieties at Kumasi for 12' stakes - , and 11,278 lbs/acre for 6' stakes on Dapam at Tamale.

There was a strong indication that the profitable limit of height of supporting stake was not reached since it appeared possible that still greater yields could be obtained by using higher stakes. Brown (1931) has also reported similar results. He suggested that weed competition might be more severe on unstaked yams, hence their lower yields.

Sexes of yam plants: About 290 plants of 6 varieties, were planted for observation at Asuansi station, (Hinson 1934). 54 produced no flowers, 11 had abnormal flowers, the sex of which could not be determined. Three varieties, Batafu, Ayirbil and Lilia, were entirely female varieties, producing no male flowers. Puna was probably a male variety and Unnamed and Akokoa produced a mixture of male and female flowers.

It is very unlikely that farmers had selected plants by examining flowers, the sole interest being in the tuber and other characters such as earliness or lateness in maturity, leaf size, presence or absence of prickles, etc. If this hypothesis is true, then it would mean that male and female plants might have produced different characters hence selection by farmers had resulted in either pure male or female plants. Where the influence of sex had no effect on plant characters of value in selection, a variety producing both male and female plants had resulted. Hinson (1934) observed that male plants produced less foliage than female plants, in the variety Unnamed.

Unfortunately no male plant produced pollen and no female seed germinate at this time. However, later germination experiments with true yam seed by Waller (1958) suggested that seeds might require a dormancy period before germinating. Though it was not stated how long this dormancy period would last, it was suggested that pricking the seed and dipping it in alcohol for a brief period would enhance germination.

Summarising the results of preliminary investigations on yam seed germination in Nigeria, Waitt (1956) has suggested that when the seed was harvest ripe, it was not germination ripe, i.e. the embryo was immature. The harvested seed would require certain conditions of type and duration of storage before germination could take place. The best germination percentages were obtained for *D. rotundata* and *D. dumetorum* seed (% germination figures were not stated) planted on the surface of charcoal.

Waitt (1957) again reported later that a storage period of more than three months was required during which the rudimentary embryo at harvest would become mature. Storage under dry conditions was found to be better than storage either under room conditions or under low temperatures.

Recent work (Doku 1965) on two *rotundata* varieties confirmed the embryonic immaturity hypothesis of Waitt, but found that at least for the varieties concerned, a storage period of two months at room temperature was required. "Satisfactory" germinations (between 35% and 51%) lasted for 6 months after which there was a sharp decline in germination. Germination temperatures of 30°C to 35°C might not only enhance germination but also prolong the period of "satisfactory" germination.

Seedlings obtained from these tests produced only small tubers after about 9 months. These were used as "seed" yams for planting in the normal way. The resulting plants and tubers resembled the parents from which the true seed was collected, though the tubers were still slightly smaller.

The biology of flowering and pollination in yams as a whole need urgent study. Our knowledge in this field is very scanty indeed, and if we are to effect any improvement through breeding, then such knowledge would be indispensable.

Fertilizer Trials: Trials throughout Ghana on various crops indicated that gains of 5% to 20% in yield could be obtained on yams with Sulphate of Ammonia at rates ranging from 60 lbs per acre to 120 lbs per acre depending on the district (Totto 1956 and Evans 1961). A more recent recommendation is 3 oz. per yam mound of Superphosphate and Sulphate of Ammonia in a 1 :1½ mixture applied at planting in a drill around the mounds halfway down (Willis 1962).

Studies on the Yam tuber beetles: Work on the Yam tuber beetle started round about 1958 (Buahin personal communication). The species involved is *Heteroligus meles*, Bilb equal *H. claudius*, klug. The adult beetles feed on the yam setts and growing tubers in the soil. The feeding holes are generally about big enough to accommodate the insect, but where the damage is great the holes are deeper. When many beetles attack a single tuber, the feeding holes coalesce and the resulting tuber is unfit for eating.

The beetles emerge from their breeding areas around water sources during late March to May. They enter the mounds, feed on the tubers, mature and then leave the mounds in late October and November to breed away from the yam fields. The eggs are laid in October-February.

In laboratory observations, the eggs were laid singly in the soil, and a single female could lay about 200-250 eggs during a life time. Incubation period was from 14-18 days and larval period, 70 to 160 days during which time moulting occurred thrice. The pupal period varied from 7 to 26 days.

A search for control measures has established that seed yams treated with 0.3% Aldrin are well protected against beetle damage but it appears the residual effect does not last long enough. Setts treated and sown in March are well protected, but setts sown in December-February should be treated in March, by opening up the mound and spraying the setts and the soil around with 0.3% Aldrin. This method though tedious is effective.

The economics of Yam Production: Some research has been made into the economics of yam production in Ghana. (Bray 1958). This crop is one of the few fully commercialized crops in Ghana. In the major producing area, farms are large, the average farm size of about 20 acres, ranging from 15 to 30, is very large by tropical standards.

From 50% to 90% of the gross farm income is derived from the sale of farm products, yams being the major crop, and others like maize, and rice are grown as supplementary crops both by interplanting and as a succession crop. Much of the work is done by hired labour, though a farmer's family may also help on the farm. Labour is paid for partly in kind and partly in cash. The average rate of a hired labourer is £35 a man year (230 days of 7 hours each). The mean family income from yam production is estimated at approximately £150 for a family input of labour on the farm of 4/5 of a man year. Some of the farm produce is, of course, consumed and this is difficult to estimate.

Average yields are estimated at 5 tons per acre and the disposal of yam is estimated as follows :—

Small useless tuber	15%
Used for extra seed (otherwise unsaleable)	15%
Stolen or otherwise disposed of	10%
Coverage for losses in transit	10%
Failure to sprout	5%
Damaged in harvesting	5%
Total unsaleable	60%
Saleable	40%

Thus 600-700 mounds planted to the acre would produce 240-280 saleable yams per acre.

Cassava.

Like Cocoyams, research work on Cassava in Ghana was started to find or breed varieties resistant to a virus disease, Cassava Mosaic, first observed near Accra in 1926, and had spread throughout the main cassava growing areas by 1930.

Cassava had been in cultivation in Ghana for over 200 years and because many varieties flower and set seed, numerous local varieties had been developed through selection by farmers.

Almost all these old varieties yield well over 5 tons per acre, have good food qualities (fufu and ampesi) and a safe level of HCN (i.e. less than 50 mg. per kg. fresh root), though some varieties may excel others in these characters probably because there were different emphasis in selection by farmers in different areas. Unfortunately, all these varieties went down heavily with the virus disease. It therefore, became necessary not only to find or breed varieties resistant to the virus, but also to combine this resistance with the high yields and good food qualities of the old varieties.

As a preliminary to breeding, a large collection of local, and of exotic varieties from Trinidad, British Guiana (now Guyana), Mauritius, Java, Kenya, Sierra Leone and the Cameroons was made. These were inter-planted with a susceptible variety in field trials on Agricultural Stations, for the assessment of their resistance. Susceptibility of seedlings was assessed by grafting buds of infected plants on to seedlings, or grafting seedlings on to infected plants.

Mechanical inoculation was not successful. It was realized that grafting gave absolute results, but was no real guide to field performance. Apart from the intrinsic ability of a plant to resist infection, there were other external factors controlling natural infection which the artificial methods did not cater for. Since, however, the element of chance was greater in natural field infection, the grafting method was used as a check on field performance when a variety's behaviour was inconsistent.

As a result of several crosses and field tests, two hybrids namely C50 and C282A were recommended as being high yielding, of good taste, and highly resistant to mosaic. C50 later went down with the disease and was replaced by Mauritius 9, a selection from an introduction from Mauritius which was later named Ankra in 1935. C282A was also later named Queen. The varieties Gari and Williams, also selected from crosses, were later added to the recommended list. Unfortunately, the parents of most of these hybrids cannot be traced.

Gari had the highest mosaic resistance and was also the highest yielder, producing very large but unpalatable tubers high in starch content. It was recommended specifically for Gari and starch production.

Queen was an all purpose type, highly resistant to mosaic with moderate yields and palatable tubers.

Williams, named after the breeder, was the most palatable variety with a fair amount of mosaic resistance and moderate yields.

Ankra was also very palatable, high yielding with a high mosaic resistance. Several cuttings of this variety were extensively distributed to all parts of the country and other parts of Africa, i.e., Nigeria, East Africa, and the Firestone rubber plantation in Liberia. (de Graft 1960, Lloyd-Williams 1957). (Yield and Resistance figures not given).

These varieties are still being grown by farmers but are very mixed, probably as a result of accidental hybridizations with other varieties. Because of this breakdown in varietal purity, or an increase in the virulence of the mosaic virus as it became more widespread through the country, all these varieties became very susceptible to the disease to such an extent that they are now used as spreaders of the disease in field trials. Ankra, by far the most popular and widely grown variety in the country today, however, still maintains a relatively high yield of between 7 to 10 tons per acre or probably more.

With the death of T. Lloyd-Williams (Plant Breeder) in 1942, A. C. de Graft, his assistant, had to continue his valuable work alone till 1948 when the latter was given a new assignment. Work on cassava was therefore discontinued till 1954 when a new Plant breeder was appointed.

By this time, results of work in East Africa where breeding had been concentrated on resistance to two virus diseases, mosaic and brown streak (the latter is not present in Ghana) were beginning to be known. It has been established there that no variety of *M. esculenta* was completely resistant to the mosaic virus. Resistance was found in other species which lacked the tuberous roots of *M. esculenta* and successful inter-specific crosses combining resistance with the desirable characters of *M. esculenta* had been obtained.

Resistance, however, was not a simple presence or absence factor, but ranged from very high resistance to susceptibility with all grades in between. (Jennings 1963). There was also a strong suggestion that the ideal of immunity might not be reached, but that highly resistant clones which would be satisfactory in respect of other desirable characters could be developed.

The mosaic virus was also found to exist in several different strains and there was always the possibility that resistance, even in a highly resistant clone, might break down and hence a high yielding, susceptible but tolerant variety might be a better proposition.

There was again a strong indication that a more virulent strain of the virus was at work in East Africa since all resistant varieties from the West Coast immediately went down with the disease when sent to East Africa. It was therefore decided to obtain some resistant material from that part of Africa to improve the resistance of Ghanaian varieties. (McEwen 1955).

Open-pollinated seeds from resistant clones (hybrids between *M. glaziovii* and *M. esculenta*) were therefore obtained from the East African Agricultural and Forestry Research Organization at Amani, Tanganyika. Selections from seedlings raised from these clones form the basis of recent breeding work in Ghana, which involves hybridizations between selected clones from the East African material, and between local varieties and the East African material, to combine high yields and good food qualities with high resistance to mosaic.

As a result of direct selections from the East African material, the following outstanding clones have been obtained namely *K.357, K 162, K.680 and K.491. *K.357* was selected in 1957. It is the most resistant clone so far, its percentage resistance ranging between 70 and 90. Its yield is rather low, about 3 tons per acre. The tubers are very palatable but of poor cooking quality *K.162* was also selected in 1957. Its resistance to mosaic is between 40% to 60% and yields about 5 tons per acre. The tubers are moderately palatable but of poor cooking quality. *K.680* was selected in 1957 from a cross between two clones raised from East African hybrid seed. Its mosaic resistance is between 15% to 25%. It is very vigorous and high yielding; yielding up to 15 tons per acre, with very palatable and good cooking tubers. This is now one of the recommended varieties in Ghana. (Ankra is the other). *K.491* is an open pollinated selection from "Tree" cassava *M. wrightii*. Its mosaic resistance is between 5% to 15% and yields up to 10 tons per acre. The tubers are moderately palatable and of a very good cooking quality.

The palatability and cooking qualities of the variety Ankra are still the standard by which other varieties are rated. Only K. 491, and K. 680 come near to Ankra in these qualities.

A hybridization programme to combine the resistance of K. 357 and K. 162 with the high yields and other qualities of K. 680 and Ankra being undertaken by the Crop's Research Institute at Kwadaso, Kumasi, is now well under way. Unfortunately K. 491 does not flower and can not be used in this programme. Results have so far, been very encouraging, and high yielding, disease resistant clones may be obtained in the very near future.

***K — Kwadaso Number.**

It has been known for a long time that resistance to mosaic is strongly linked genetically with low yields. In fact, many decades of attempts to combine high yields with high resistance have not proved very successful. This combination lasts for a few years only, after which the varieties become susceptible and probably, go down in yields as well. On the other hand, in Ghana at least, there are many high yielding but very susceptible local varieties, the most outstanding among them being Ankra.

Investigations into plant characters associated with yield have indicated that at least, in some varieties, the ability to retain a large number of leaves and a large green stem area during the most favourable season of the growing period may be more important than high disease resistance per se in bringing about high yields. (Doku 1965). This work needs following up to find out how these plant characters could be incorporated into the breeding programme to combine high resistance with high yields and good food qualities.

The yield of starch of varieties in Ghana has also been considered. Local varieties are almost entirely of the sweet type and are lower in starch content as compared with the high yielding, bitter varieties of Latin America and the Far East which are mainly grown for the commercial production of starch. It may well be that only the sweet types were brought from Brazil to the West Coast of Africa. In fact, *Captain Philip Beaver in 1792 mentioned in his "African Memoranda" that he found only sweet cassava on the Island of Bulama (on the West Coast of Africa.). This made a profound impression on him because he had found no sweet cassava in the West Indies. It is also likely that over the years, in selecting for palatability, farmers had concentrated only on the sweet types.

The yield of starch is closely related to the overall yield (fresh weight) of tuber, as well as to its moisture content. The ideal variety must be high yielding, producing tubers of very low moisture content. For, if the yield of tuber is low even if the starch content is high, the yield of starch per acre is bound to be low. Similarly, if the yield of tuber is high, and the moisture content also high, the yield of starch will again be low.

Trials of Kwadaso with over 200 varieties, clones, and hybrids have suggested that there might be no relationship between yield and starch content, and between yield and moisture content. The relationship between moisture and starch content might, however, be significantly negative. That is to say, a variety stored water in its tuber at the expense of starch and vice versa. Yield (fresh weight) of tuber, however, was not affected whether more starch or more water was stored.

However, since the moisture content of many local varieties appeared to be more or less the same, i.e. between 50% to 60%, it would appear that another tuber characters, apart from moisture content might be responsible for variations in starch content. A tuber, minus its outer and inner skins, is made up largely of water, starch and fibre. In the course of tuber development, an internal meristem, centripetally proliferates parenchymatous cells (in which the bulk of the starch is stored) studded irregularly with vascular bundles of various sizes. These bundles which determine the fibre content of a tuber are also largely responsible

* Beaver, Philip (Captain) An African Memoranda relative to the attempt to establish a British settlement in the Island of Bulama on the West Coast of Africa. Printed for C. & R. Baldwin. 1805.

for supplying the tuber with water. Many varieties may have the same moisture content and the same concentration of starch per unit tuber volume, but different amounts of fibre, depending on the sizes and numbers of these bundles. Some may have large numbers of smaller bundles, others a few large bundles, and so on. A few large bundles make up a smaller fraction of the overall tuber weight than numerous small bundles. Therefore, if the composition of tubers is equal in every respect except in fibre content, one would expect the tuber with the least weight of fibre to have a higher starch content and vice versa.

It is interesting to note that these same bundles to a large extent, determine the cooking qualities of a tuber, many bundles giving rise to "stringy" tubers. A tuber with fewer bundles should therefore be preferred. It might therefore be expected that tubers of local varieties with good cooking qualities should also be relatively high in starch content. This has been clearly borne out in trials at Kwadaso. Of 255 varieties, clones and hybrids on which determinations were made, 67 had percentage starch content values of 10% and above. Of these, the already established (good cooking) varieties were among those with the highest values. E.g. Nkani, 11.0%, Ankra, 15.5% and Calabar red tuber 16.5%.

In addition to breeding for high yields mosaic resistance and good food qualities, it is necessary to develop high starch yielding varieties for the commercial production of starch and alcohol. This line of work needs urgent attention now.

Some work has been done on the mechanisation of the crop at the Pokoase Agricultural Station by Evans (1957). Trial plantings were done by two persons sitting on a low platform behind a tractor with a load of cuttings. At pre-determined intervals (3 feet) marked by the tractor, each person inserted a cutting into the soil at the point marked. Two ridges at a run (each person planting a ridge) were planted in this way. This is a quick and easy method which could be widely used. Trial harvesting was also done with a mid-mounted disc plough, digging under a ridge, loosening the earth, and exposing the tubers to be picked up later by hand. This operation presented some difficulties. First of all, tall cassava stems had to be cut short to make it easier for both driver and tractor to operate. Secondly, most of the tubers were cut through by the discs since they were not only at different depths but also of different shapes and sizes. The lower portions of the cut pieces were often left to rot in the soil because they were not always seen by the pickers. Yields were therefore reduced as a result.

In later trials at Pokoase in 1962 by Kumar (1962), the cassava sticks were first cut by a mid-mounted mower instead of by hand. It was also found that the mid-mounted Disc-Terracer could harvest an acre in 2¾ tractor hours for which five man-days were normally required. The planting unit was also modified so that six ridges could be ridged and planted at the same time, after the field has been ploughed and harrowed. The average time taken to ridge and plant one acre in one operation was 2 hours and 10 minutes as compared to 4 man-days per acre for planting alone. Losses due to damaged or incompletely dug out tubers were not mentioned. The advantages of mechanization particularly when large acreages are involved are obvious nevertheless.

As soon as cassava tuber is cut through it must be used immediately or else it will start to deteriorate. The possibilities of harvesting cassava mechanically are therefore remote at the present time when there are no mechanized processing plants to handle large harvests at a time. Moreover, we are far yet from developing varieties with the right tuber shape and size amenable to mechanical harvesting—more rounded than elongated. However, there are a number of dwarf varieties such as Poe and Kromho whose stems need not be cut back before harvesting. Short or round tubers may have to be developed from these. How long this will take cannot be predicted. All indications are that it may not be an easy task since these dwarf varieties may be poor yielders.

The Irish Potato (Solanum tuberosum)

It would appear that before 1898 Irish potatoes were being cultivated in Ghana. In his book "Gold Coast Past and Present" George MacDonald (1898) then Director of Education writes (page 51) . . . . "In other parts, the people gave their attention to the cultivation of Corn, Yams, Potatoes, Plantain, Bananas and the preparation of Palm oil. It would be very difficult to find at the present day a potato grown on the Gold Coast; rice is now very largely imported but much attention is still given to the cultivation of the yams, cassava and the sweet potato."

It is not clear whether MacDonald's observation on the disappearance of the potato was his own experience or whether he was relying on what others had told him. Though MacDonald distinguished between the potato (Irish) and sweet potato, others did not always do so. Indeed, very few writers distinguished between *S. tuberosum* and *Ipomoea batatas* in those early days. They merely mentioned "the potato." Most of them were merchants and traders not botanists or agriculturists interested in crops *per se*. It is therefore, not unlikely that MacDonald might have relied on information obtained from one of those people who could not, or did not care to distinguish between the different species of potato.

Cofie (1949) who genuinely believed MacDonald and thought that Irish potatoes were being widely cultivated in the country prior to 1898, cites the results of two rather inconclusive experiments, his own, Cofie (1949) and that of Glover (1947), to support this belief. No yield figures are given in the report by Cofie which covered a two-year period (1942-1944) of trials conducted at Amedzofe, 2,400' above sea level and Gbefi (near Kpandu) 500' above sea level. He concludes :

1. "For good yields a heavy and well distributed rainfall is required from planting to tuberization. Thereafter, and up to maturity, that is until the tops commence to die, rainfall need not be so heavy, but it should be well distributed."

2. "Comparison between yields at places of low elevation and of high elevation should be relative and not absolute. With good rainfall satisfactory yields should be obtained at places of low elevation."

Cofie, thus admits however reluctantly, that yields at lower altitudes are lower than those at higher altitudes.

Though Glover (1947) also concluded that potatoes grown at 3,000' and 600' above sea level on latitude 5°S in Tanganyika from Kenya grown commercial seed, could give yields of ware similar to English yields provided (a) the soils were manured on a scale comparable to that of moderate English practice and (b) the plants received water throughout life, yet it was only the yields of ware obtained from well manured plots at the higher altitude which came nearer to English yields. Here he obtained 6.1 to 7.5 tons per acre in the relatively dull season and 6.5 to 9.6 tons in the hot bright season.

The overall mean yield obtained from the lower elevation was only 3.5 tons per acre. This is certainly poor by English standards, yet Glover thought this figure was "surprisingly large because most of the plants died of drought before reaching maturity."

Since the trials were not repeated, and we are not told what the yields would have been under favourable conditions at the lower elevation, too much reliance should not be placed on Glover's conclusions. Knowing fully well that the growing of Irish potatoes at lower elevations in the tropics had always been a problem, he could have made his report more convincing, had the results justified his doing so. Obviously he could not.

Again in support of MacDonald, Cofie (1949) writes . . . "It is difficult to believe that the cultivation of potatoes (Irish) was then (i.e. prior to 1898) confined to places of high elevation. It would be interesting to know why its cultivation was abandoned. Bad husbandry, incidence of disease with consequent low and unprofitable yields suggest themselves as the chief reasons. At the present time wherever the potato has been tried by the department of Agriculture, Leaf roll —a virus disease, and Sclerotium have shown up in the plots and caused appreciable losses in yield."

If one agrees with MacDonald (1898) and Cofie (1949) then one might conclude that the first attempt to grow Irish potatoes in Ghana was a complete failure. One should, however, bear in mind that it is also possible that the crop had not been introduced by that time since there is no corroboration from any other source regarding the authenticity of MacDonald's observation.

One could be very certain, however, that by the early 1940's Irish potatoes were being planted by the Department of Agriculture at various places in the country. (Blane 1951 and Manser 1962) — all at high altitudes, e.g. Mampong, Ashanti 1,300' above sea level and Amedzofe 2,250' — 2,400' above sea level, primarily to augment the war time shortage of importations into the country. But since it was largely held (and it is still held) that the Irish potato was nutritionally more superior, especially in protein content, than all the tropical root crops, so much was done on the Irish potato, that within the short span of a decade and a half (i.e. 1940-1955) a large number of experiments was conducted on this crop almost to the neglect of the tropical root crops. (Sekyere 1965, Blane 1951, Cofie 1948 and 1949, Miller 1962, Manser 1962 and Anon 1936).

The following trials summarised by Sekyere (1965) were some of those carried out during this period, mainly at Mampong Station 1 Variety trials, 2 Generation trials 3 Seed treatment trials, 4 Time of Planting trials, 5 Application of Mulch and Farm yard Manure and 6 Storage trials.

Yields in all these trials were very low not only by European standards for Irish potato but also compared with the average yields obtainable for the important tropical root crops, i.e., Cassava, Cocoyams and Yams. The highest yield obtained were 5.8 tons per acre. Indeed, yields of the order of 5 tons per acre were very rare, except in the heavily Mulched and Farmyard Manure trials where such yields occurred more frequently, the highest yield being 5.7 tons per acre when manured with 7½ tons per acre of Farmyard Manure and 10 tons per acre of Mulch.

Moreover, most of the trials were either "observations" from small plots sometimes of less than 1/100th acre, or not properly designed. Results of these experiments, therefore, should not be relied on too much. In all probability yields per acre were inflated by the smallness of the plots.

The failure of this attempt to grow Irish potatoes in Ghana is borne out by the fact that by the end of 1958, the Department of Agriculture had ceased to be enthusiastic about the crop, and that the farmers' co-operatives organized to grow the crop in the Mampong Ashanti district had long ceased to function, obviously because they were not making profit, the war having come to an end and cheaper potatoes were being imported again from abroad.

To conserve the drain on our foreign currency reserves, The State Farms have since 1963 embarked on large scale potato cultivation with seed imported from Western Europe. An observation from the previous trials was that two-thirds of the cost of growing potatoes was due to the cost of imported seed. (Cofie 1948). It is, however, too early yet to comment on this new large scale potato enterprise, though experience of previous plantings should normally make one less optimistic about its success. Naturally most people in the tropics are eager to eat Irish potatoes because of the old belief that it is more superior nutritionally than most of our tropical root crops. That this belief is deep rooted and dates far back would be seen by an article entitled "Potato for the Tropics," from the Gold Coast Farmer (1937) 6, 216, culled from the Crown Colonists of November, 1937. The relevant portion is quoted ". . . . Among research projects of particular interest that are being financed is a search for new varieties of the potato (Irish) suited or capable of adoption to tropical conditions. Such a foodstuff it is believed would be of the greatest importance to the Colonial Empire in view of the nutritional superiority of the potato over many of the tropical root crops. A free grant of £100 is, therefore, being made to the government of Jamaica so that a special officer can be attached to a scientific expedition which is being sent to Peru."

Another article entitled "Potato breeding and Research,—South American Tropical Species,"—which appeared on page 48 of the same volume of the Gold Coast Farmer and which was culled from the Imperial Bureau of Plant Genetics. 8, 633491, will throw more light on what should have been done to obtain potato varieties suitable for the tropics, particularly areas of lower elevation. It reads :—

"Hitherto it (the Irish Potato) has been regarded as a temperate climate crop capable of growing in countries with conditions like those of Northern Europe. It now appears that the vast majority of potatoes in their native home belong to the tropical belt and are adapted to all the conditions including the short photoperiod found in the tropics. Most of them occur in mountainous areas but one specie. S. *Phureja* is found in hot valleys at low latitudes and forms tubers in humid hot, sub-tropical conditions. It is characterized by a low starch content (8-10%) but very high in protein (14%). Potato breeding in Kenya, India and other countries near the equator should therefore be based on this Andean material rather than on types obtained from Scotland, etc. as has been the practice ; a great extension of potato cultivation in the tropical and sub-tropical countries may be foreseen as a result."

There is no record of any breeding work in Ghana involving *S. Phureja* types as suggested. Miller (1962) mentioned that a consignment of seed and seed tubers of other solanum species and crosses was received at Mampong from Cambridge but they all failed to germinate or sprout. Apparently no further attempt was made to obtain fresh material. In fact, it appears no serious attempt anywhere in the tropics has been made to breed potatoes adapted to lowland tropical conditions and it is high time something was done about this. For, it appears we must either grow the right types of Solanums or not at all. Moreover, in Ghana, had half the time spent on experimenting with imported potato seed from Western Europe been devoted to experiments on cocoyams and sweet potato, we would obviously have obtained better varieties with higher yields than we have today. At present we have lost in both fields of endeavour.

Nor is the Irish potato as nutritious we have been made to believe. The following table (Table 4) shows that is not. From it, it would be seen that the Irish potato contains the same amount of protein as yams and cocoyams. Yam flour, in fact, contains more protein than the Irish potato, whose protein content is only 0.5% higher than cassava flour (kokonte) and sweet potato. As regards Minerals and Vitamins, Irish potato is lower in calcium and iron than all the tropical root crops except fresh yam with which it has the same calcium content. Sweet potato and yam (fresh) contain considerably higher quantities of vitamin A than Irish potatoes. The Thiamin content of Irish potato is the same as that of the tropical roots except cassava whose thiamin content is lower. The Riboflavin content of Irish potatoes is almost the same as the tropical roots. Its nicotinamide content is slightly higher whilst its ascorbic acid content is only slightly lower than that of fresh cocoyams and yams.

The Net Protein Utilization (N.P.U.) values of all the tropical roots are very low, that for Irish Potato, I am reliably informed, (Oracca-Tetteh Personal) is of the same order. They are all inadequate for health and must be supplemented by protein rich foods, i.e. fish, meat, eggs, etc. Europeans themselves have never regarded the Irish potato as a complete food, but mainly as a source of carbohydrates, just as the tropical roots are regarded.

We should therefore, eradicate this "Potato" mentality and concentrate more on the improvement of our root crops. They have all the advantages of yield, adaptation, and ease of cultivation over the Irish potato. Besides, they are the already established staples. It is not only their roots which are eaten but other parts of the plants as well, e.g. the tender leaves of the cocoyams are a valuable spinach in Ghana eaten almost daily by the majority of the people. The young leaves of the cassava also serve the same purpose in other parts of West Africa. The many products prepared from cassava roots are well known everywhere. What is not so well known, perhaps is that the peel of cassava is a valuable feed for sheep, goats and pigs in West Africa.

Clonal selection in yams and cocoyams could result in better varieties than those being grown at present. Research into methods of inducing flowering and seed setting in these crops should also be vehemently pursued. Fortunately the problem of flowering and seed setting does not appear to be very serious in cassava and sweet potatoes. It is indeed strange that more breeding work has been done on sweet potatoes in the temperate regions where seed setting is more difficult than in the tropics. These temperate workers have shown that sweet potatoes grown from seed, exhibit great diversity in their characters, and whenever the problems of seed production are overcome, the breeding potential of the plant may be considerable. (MacDonald 1963). Prolific seed production has been reported in Kivu, (Congo Kinshasa), Buganda, and parts of Hawaii. Working Hawaii, Poole, (quoted by MacDonald 1963) produced two unique plants with 75 and 65 tubers weighing 20.5 lbs and 27.5 lbs respectively. It is high time Ghanaians started being interested in this crop. We should not forget that Carver (1936) the famous American Negro agriculturist, reported 118 different, attractive products made from this crop.

If, inspite of the many advantages of the tropical roots we must, for other reasons, grow Irish potatoes in the tropics, it should not be by imported seed from the temperate regions. We must first of all turn to such species as *S. phureja* and *S. rybinii* which are known to grow well under condition of high temperature and humidity and start a comprehensive breeding programme to obtain varieties capable of growing and producing well under our conditions.

It will not be an easy task, but a long and arduous one. It will also be a challenge which must be taken up by breeders in the tropics. Taking their inspiration from what has been done on other crops elsewhere, e.g. Maize in the U.S.A., Wheat, Barley and Oats in Western Europe—all crops originating from climates different from that of Europe — they should press on and demonstrate to the world once and for all whether or not tropical solanum varieties could be bred, capable of yielding as well as the other tropical root crops.

*Table 1. *Estimates of Acreages of Main Staples (Thousand acres).*

Crop	Northern Territories (Now Northern and Upper Regions)	Ashanti (Now including Brong/Ahafo)	*Colony (Now Southern Ghana) Forest	*Colony (Now Southern Ghana) Non-forest	Togoland Ho District (Now Volta Region)	Total
Maize	79.5	66.7	87.0	100.1	21.0	354.3
Millet	432.0		—	—	—	432.0
Sorghum	332.5	—	—	—	—	332.5
Rice	20.5	6.5	5.5	8.6	6.2	49.0
Plantain	—	67.9	231.3	—	16.5	314.0
Cassava	1.5	45.7	56.8	92.5	8.2	204.7
Cocoyam	—	45.4	144.9	5.5	4.0	199.8
Yam	59.5	58.4	15.3	6.4	9.4	149.4
Groundnut (seed)	11.5	21.9	—	—	—	—
Pulses	39.0	—	—	—	—	—
	*1,076.0	312.5	540.8	213.1	69.2	2,111.6

*From Annual Report, Dept. of Agriculture, Gold Coast, 1950-51 (1952) p. 23.

*Table II. *Estimates of Production of Main staple (Thousand tons)*

Crop	Northern Territories (Now Northern and Upper Regions)	Ashanti (Now including Brong/Ahafo	*Colony (Now Southern Ghana) Forest	Non-forest	Togoland Ho District (Now Volta Region)	Total
Maize	29.0	33.4	43.6	50.0	10.5	166.5
Millet	97.0	—	—	—	—	97.0
Sorghum	78.0	—	—	—	—	78.0
Rice	9.5	3.0	2.5	—	7.5	22.5
Plantain	—	271.6	925.2	34.6	24.8	1,256.2
Cassava	4.5	119.9	149.1	209.1	21.6	504.2
Cocoyam	—	115.8	369.6	14.1	10.1	509.6
Yam	204.0	175.2	45.7	19.2	29.5	473.6
Groundnut (seed)	22.5	6.0	—	—	—	29.5
Pulses	31.5	—	—	—	—	31.5
Total	476.0	724.8	1,535.7	327.0	105.0	3,168.5

*From Annual Report, Dept. of Agric. Gold Coast 1950-51 (1952) p. 23.

*Figures of production and acreages are taken from the 1950-51 Annual Report by the Department of Agriculture and are only estimates. However, they more or less agree with what is generally known through observations.

Table III. —Proportionate Distribution of Expenditure within the Group "Local Foods" All items equal 100.00.

Commodity	Sub-group %	Item within Sub-group %
Cereals (Grain)	6.55	
Corn-whole/shelled	—	2.83
Guinea Corn	—	0.20
Millet	—	0.35
Rice	—	3.17
Cereals (Prepared)	10.45	—
Corn (Maize)	—	—
Dough or Ground	—	0.93
Kenkey, Akple, Koko, Abole	—	7.91
Krakro, Tegbei, etc.	—	0.61
Bread (from home ground grain)	—	1.00
Rice and Beans or stew, twuo	2.75	2.75
Roots and tubers	15.82	—
Cassava	—	6.81
Cocoyams	—	2.07
Sweet potato	—	0.05
Yam	—	6.89
Cassava (prepared)	5.46	—
Dough	—	0.91
Kokonte	—	2.28
Gari, Yakuyaku	—	0.10
Agbli kakro	—	0.17
Nuts	1.85	
Oils and vegetables	3.00	
Fruits	7.67	
Pulses	0.55	
Vegetables	9.02	
Fish	18.53	
Shell Fish	0.57	
Meat and Poultry	14.00	
Livestock	0.90	
Miscellaneous	3.50	

From Economic Bulletin (1962): 6, No. 4.

Table IV. ***REPRESENTATIVE VALUES PER 100 gm EDIBLE PORTION***

	WATER (ml.)	CALORIES	PROTEIN (g)	FAT (g)	CARBOHYDRATE (g)	FIBRE (g)	CALCIUM (mg)	IRON (mg)	VITAMINS: A, Potency (I.U.)	VITAMINS: Thiamine (mg)	VITAMINS: Riboflavin (mg)	VITAMINS: Nicotinamide (mg)	VITAMINS: Ascorbic Acid (mg)	Waste % of food as purchased
Cassava Fresh (M. esculenta)	60 (45-74)	153	0.7	0.2	37	1.0	25	1.0	0	0.07	0.03	0.7	(0-50) 30	15
Cassava Flour	12 (11-15)	342	1.5	0	84	1.5	55	2.0	0	0.04	0.04	0.8	0	0
Irish Potato (S. tuberosum)	80 (70-85)	75	2.0	0	17	0.4	10	0.7	0	0.1	0.03	1.5	(5-30) 15	15
Sweet potato (I. batatas)	70 (60-80)	144	1.5	0.3	26	1.0	25	1.0	100	0.1	0.04	0.7	30	15
Yam, fresh (Dioscorea spp.)	73 (54-84)	104	2.0	0.2	24	0.5	10	1.2	20	0.1	0.03	0.4	10	15
Yam flour	18 (13-19)	317	3.5	0.3	75	1.5	20	10.0	0	0.15	0.1	0.1	0	0
Cocoyam (X. Sagittifolium)	65 (58-78)	131	2.0	0.3	31	1.0	20	1.0	0	0.1	0.03	0.5	10	20
Cocoyam (C. Antiquorum)	70 (60-83)	113	2.0	0	26	0.5	25	1.0	0	0.1	0.03	1.0	5	20

0 — Contains none
0 — Contains too small a quantity to be significant in dietary evaluation.

From tables of representative values of foods commonly used in Tropical countries. London H.M. Stationery Office, 1963.

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DISCUSSIONS

Dr. Rogers :

Amongst the cassava varieties, do the farmers make any distinction amongst their varieties, concerning the prussic acid or the HCN content?

Mr. Doku :

No, they do not. I suppose that HCN is related with palatability or sweetness, the more HCN, the more bitter they are. Most of our varieties are on the sweet side.

Dr. Rogers :

Is there a standard processing methodology used by the natives to prepare such things as foufou.

Mr. Doku :

Well, I suppose so. I should say that there is a standard practice of boiling and beating to a paste. The boiling is supposed to remove the HCN. It is very volatile.

Dr. Rogers :

Is grating of the tubers a usual practice?

Mr. Doku :

There are two types of foufou. In Sierra Leone, what we call foufou is different from foufou in other parts of West Africa. In Sierra Leone the cassava is first grated and made into a dough and put into boiling water, and stirred into a thick constituency. In other parts of West Africa the cassava or coco yam is boiled first and then pounded into a paste.

Dr. Rogers :

You did not make any mention at all of practices that had been reported, namely that the foliage of these plants is utilised. What do you think about this? Is this a standard practice, or what?

Mr. Doku :

I am sorry that I did not mention this. In Sierra Leone, it is not general in all parts of West Africa, it is a standard practice to use the young foliage. In Ghana the young shoot of **Xanthosoma** is used as a spinach. It is very popular. And the dry peel of the cassava is fed to livestock — goats, sheep and so on.

Mr. Gooding :

I find myself in considerable sympathy with Dr. Doku's last point about English potatoes in the tropics. We have a very wide variety of very good tuber roots and, as was shown in one paper this morning, sweet potato can have extremely high nutritive value and I don't think that you will find 'English' potatoes anywhere that can match up in general, in nutritive value with some varieties of sweet potato. Nevertheless, rightly or wrongly, there is a demand for them. In many cases, for the wrong reasons, we are seeing a demand arising in Barbados which, in my opinion, is largely because they have a certain snob value. However, the demand is there to the extent that a small country like Barbados is importing something like a million dollars worth of English potatoes a year, which is absurd. But there it is. So what are we to do? We can either have a complete prohibition of imports, in which case, people will complain that their standard of living is being arbitrarily cut, or we could carry out research intended to try to supply this from local sources which, of course, is what we have to do. I think it wrong but we have to do it. So I am in considerable sympathy with Dr. Doku on this, but we find ourselves in this same situation. May I suggest that you might be interested in trying the same variety that is showing fairly substantial promise in Barbados at the moment. An American variety called Redlasoda, which was developed, I believe, in Louisiana and has proved to be of considerable importance in the Florida potato industry, being suitable for summer growing

Chairman :

It looks as if we should have a sociology section in the next symposium.

Dr. Trujillo :

In view of the fact that **Pseudomonas solanacearum**, the cause of bacterial wilt in the tomato, is widely spread in tropical soils, I wonder if the Irish potato will be a crop of any importance in tropical areas? I'm talking now, about lowland elevations. This bacteria operates very well when soil temperatures are above 75°F and so this is rather doubtful, that any of the varieties that are available today, have any resistance to this disease.

Mr. Doku :

I must say that in Nigeria they are growing potatoes quite successfully on the Bauchi plateau. Mr. Coursey might wish to comment on it, but he was telling me that disease has started to creep in. I believe that there might be a resistance to this. We do not know, so that we shouldn't rule that out completely.

Dr. Spence :

While I agree with Dr. Trujillo that bacterial wilt has to be taken into account, there are a number of races of bacterial wilt. I am not sure that the potato one is necessarily the same that is most widespread in the tropics. But certainly it is something that one will have to take into account in the 'Irish' potato work.

Mr. MacDonald :

Just as a point of information. In Kenya the pseudomonas bacterial wilt is causing havoc with Irish potatoes, and causes the complete death of the plant, and once the soil is infected, you have to abandon it for potato cultivation. Breeding has done in the national laboratories, agricultural laboratories, just outside of Nairobi, and although this work has only been going on for about three or four years, I am told that resistance is being found amongst seedlings and they are now being selected for their tuber qualities.

Sr. Montaldo :

I will give you some more information. In Venezuela we are planting potatoes and we consider potatoes as a tropical plant, as we are planting it at 25°C, and we have no problems with bacterial solanacera. We have it under 20°C in about 1000 metres of altitude, but in the lower parts, 500 metres with 25° we have problems only with Phytophtora infestans but we can control it very well.

Mr. Pilgrim :

Mr. Chairman, I am very interested in that point which you made including a sociological factor when discussing such matters as root crops in the tropics. This matter, e.g. of Irish potatoes, Mr. Gooding mentioned the fact that there is a certain snob value attached to Irish potato in Barbados. This is true. However, there are other factors which also play a part. There is the fact that the marketing of Irish potato is so much better organised than the marketing of local food crops. There is a very powerful and very efficient mercantile community marketing Irish potatoes. It is easy for the housewife to purchase 1 lb. ½ lb, 2 lbs of Irish potatoes, but it is not so easy to take a yam weighing 5 lbs and chop it into five pieces. The 'Irish' potato keeps well and cooks easily, so there are many factors involved.

Mr. Haynes :

There is one other comment that I would like to make about 'Irish' potatoes. We have been growing most of these roots crops here, both in experiments and in commercial production. We find that we can grow a crop of 'Irish' potatoes at half the cost input that we require for any of the other crops when these are grown on a commercial scale. It is quite true that on subsistence scales, the economics is rather difficult, but the relative costs of inputs between 'Irish' potatoes and the root crops must be borne in mind.

Dr. Iton :

Mr. Chairman, I should like to make a small contribution continuing what Mr. Pilgrim has indicated about the sociological implications of growing 'Irish' potatoes. The problem of storing these root crops is a serious one in the tropics. I should just like to indicate to you, from my experience with the storage of sweet potatoes, that there is considerable advantage in producing crops like the 'Irish' potato.

The example to which I refer is the sweet potato crop in St. Vincent. This crop is grown at about 5 crops in two years on the same land. There is considerable build up of soil fungi, which attack the tubers, remain latent until after harvesting and develop very rapidly, and disastrously on tubers shipped from St. Vincent to Trinidad. There was a particular example of tubers harvested in St. Vincent on Friday, and shipped to Trinidad to arrive on the retail market by the following Tuesday. In that short space of time, as much as 26 to 37% of the tubers were lost because of black rotting.

Now this is quite a serious problem. The housewife will not buy black rotted sweet potatoes, however slight the attack is. But in crops like 'Irish' potatoes, storage does not present the problem that some of our root crops in the tropics present. So despite the fact that there may be high nutritive value in sweet potatoes, there is the problem of very rapid deterioration in storage and in transit.

STATUS OF ROOT CROP RESEARCH IN THE PHILIPPINES

— *by* —

Cresencio D. Molinyawe

This paper aims to assess the status of root crops research in the Philippines based on the work done on this group of crops. For the first time a critical analysis of the results of experiments is presented as well as data of some important applied researches.

Studies involving some of the cultural practices with root crops are rather limited. Most workers have conducted variety tests; several have carried fertilizer trials, and a few have studied processing, storage and utilization. However, the data on some of these subjects were either extremely meager or nonexistent.

Before I go further let me assess the food supply situation in the Philippines.

Food Supply Situation in the Philippines

The average annual gross available supply of food items in 1965 amounts to 11.5 million metric tons of which 9.7 million metric tons or 84.1% is of plant origin and 1.8 million metric tons or 15.9% is of animal origin. Of the food items derived from plant resources about 9.0 million metric tons or 92.8% is produced in the country and 7.2% is imported. About 43.5% of the total food crops produced is cereals; 17.0% is root crops and tubers; 18.0%, fruits; 9.6%, vegetables and 11.9% sugar, dry beans and nuts.

Root and tuber crops are the second suppliers of carbohydrate foods in the Philippines with a total production of about 1.5 million metric tons. About 208,000 metric tons of starchy roots and tubers produced in this country are used for non-food purposes leaving 1,314,000 metric tons available for human consumption. This is equivalent to per capita supply of 43.1 kg per year or 118 grams per day. Actual intake of starchy roots which amounts to an average of 42 grams per capita per day shows that it is almost one-third of the per capita supply. The wide gap existing between the actual intake of roots and the supply indicates a possibility that a large quantity of the country's supply of starchy roots and tubers for food is not actually utilized for that purpose.

Except in a few places of the country, root crops are used only as substitute food when the supply of rice and corn is low and price of these cereals is high. Practically all of the supply of starchy roots in this country is produced locally. Of the total root crops produced, about 51.9% is sweet potato, 35.7% is cassava and 7.0% is gabi or taro. The rest or about 5.4% are ubi, tugui, arrowroot and yauntia. (Anonymous, 1966).

RESEARCH ON CASSAVA

Originally the cassava tuber was a main food crop among Latin-American people. At present it is grown as a substitute for rice or alternately with rice on large acreage in regions where, for centuries, rice has been the sole crop.

Realizing the importance of cassava in this country, the U.P. College of Agriculture began the study of its culture in its early history. Foreign varieties have been introduced and assessed. Analyses were made on the storage roots. Also, processing and utilization of this root crop were studied. The possibility of alcohol and starch extraction were undertaken and recently experiments on the value of cassava as a livestock feed have been done.

Guanzon (1927) expounded on the possibilities of cassava production in the Philippines. He enumerated the following reasons:

1. Cassava is a very easy plant to grow under most field crop conditions in the country.
2. There is an exact parallel between the planting and cultivation of sugarcane and cassava.
3. Cassava has many advantages over sugarcane which few people seem to realize.
4. Simple machines for starch processing are needed.
5. Local demand for cassava exists.
6. It is a cheaper source of starch than corn.
7. Cassava is not a permanent crop.

To promote the processing of cassava flour, the Philippine Congress passed in 1951 Republic Act 657 known as the Cassava Flour Law (Acena 1953). Section 1 of the said act states that, "it is declared to be in the interest of the country's economy and development of its agriculture and industry, to encourage and promote the production, processing and consumption of cassava flour as a measure to conserve dollars to prevent the scarcity of wheat flour and to regulate its importation consistent with the commitments of the Republic of the Philippines under the International Wheat Agreement".

Propogation

Guanzon (1927) pointed out that any part of the cassava stem may be used for propagation, including the stumps, but the best part is the mature portion of the stem with the exception of that nearest the root and green portion at the top. Mendiola (1931) stated that in planting cassava, the young top portion is removed while the remaining part is cut into pieces and used for planting. The bottom pieces seem to be better than the upper cuttings as planting materials.

Galang (1931) reported that the average yield of roots per hectare of base cuttings obtained in a trial planting was 36.5 tons, of the middle, 34.9 tons and of the apical cuttings, 19.7 tons. From there he suggested the use of the base and middle portions of the stem for planting.

Certain planters claimed that longer cuttings are better than the shorter ones. Planting the entire stem will reduce the expenses for labour. In order to determine the effects of planting the entire stalk upon the yield of cassava, Palis (1938) conducted an experiment on this aspect. Some of the important results of the experiment were given below:

	Entire Stalk	Ordinary cuttings
Yield of roots per hectare (tons)	32.99	30.13
Yield of starch per hectare (tons)	3.45	2.97
Yield of cuttings per hectare (meters)	69,935.60	84,302.40

The entire stalk planting produced more plants and yielded more storage roots and starch than the ordinary planting. However, the stalks from the former were shorter and more slender.

Huertas (1940) studied the effect of age of cutting on the yield of cassava. Old cuttings (near the base) gave better stand and more root yields than the younger ones (upper cuttings towards the tip). The results are shown on Table I.

Table I. Percentage germination, yield of roots and starch in tons as affected by age of cassava cuttings (Huertas, 1940)

Group	Cutting No.	Germination %	Yield of roots/ha T	Starch yield/ha T
Top	1	15.1	4.4	0.57
	2	45.2	15.6	1.81
	3	63.9	19.6	2.25
Middle	4	74.1	18.2	2.21
	5	77.0	19.7	2.12
	6	82.4	19.2	2.07
Base	7	82.1	19.4	2.02
	8	82.5	18.5	2.01
	9	82.7	21.4	2.31

Intercropping

Martinez (1947) found that intercropping corn with cassava between the rows and hills gave a fairly good yield of roots when the two crops were planted at the same time (Table II).

Harvesting

Soliven (1921) determined the effect of age or time of harvesting on the starch content of six varieties of cassava. When the plants were over-matured, there was a decrease in the amount of starch (Table III).

Sison (1921) has a similar study but he determined the effect of the yield of roots (Table IV). There was an insignificant increase in the yield of roots among the varieties from the 11th and 12th month after planting except Aipin Mangi.

Table II. Effect of intercropping corn with cassava

Treatment	Cassava kg	Marketable ears kg	Non-marketable ears kg
Ordinary field:			
1. Corn alone	-	930.7	2185.8
2. Cassava between hill of corn after the latter was hilled up	1115.9	909.3	2214.3
3. Cassava between rows of corn after hilling up	707.2	863.5	2220.1
Bulldozed field:			
1. Corn planted alone	-	641.3	747.6
2. Cassava planted between hills of corn at almost the same time	2286.3	884.8	1142.6

Table III. Starch content of cassava varieties as affected by age of harvesting (Soliven, 1921)

Variety	Age	% starch (air-dry basis)	Variety	Age	% starch (air-dry basis)
	10	77.15		10	75.36
	11	78.45		11	75.50
Aipin Mangi	12	87.90	Angular	12	81.00
	13	99.60		13	76.27
	14	73.10		14	59.22
	8	68.50		10	76.20
	9	76.50	White Smooth	11	77.12
Aipin Valenca	10	84.31	Intermediate	12	79.04
	11	84.00		13	69.00
	12	84.10		14	66.40
	13	75.05			
	8	67.66		7	70.65
	9	83.16		8	71.60
	10	91.09	Red	9	82.50
	11	86.46		10	75.60
	12	79.00		11	70.48

Table IV. Storage root yield of different cassava varieties as affected by age of harvesting (Sison, 1921).

Variety	Age at harvest (in months)		
	10	11	12
Kapo Colorado	7140	9960	10840
White Smooth Intermediate	8640	12360	12300
Angular	9280	12940	13860
Rough Intermediate	10640	13280	14320
Kapo White	11260	11740	15220
Casjave Singkong Manis	12980	15120	16140
Aipin Valenca	18320	20320	20970
Aipin Mangi	19200	22620	35700
Mandioca Basiorao	36060	37780	38280
Mandioca Sao Pedro Preto	27880	37180	38500

In a study at the U.P. College of Agriculture on the relation of age of cassava plants to their yield of roots and starch, Uichanco (1959) stated that the percentage of commercial starch decreased as the plants grew older (Table V).

The highest yield of roots and starch was obtained when the plant was fourteen months old, in the case of Seedling No. 2152. The maximum yield of roots of Aipin Valenca was obtained when the plant was fourteen months old but the maximum production of starch was obtained at the twelfth month.

Storage and Processing

Baybay (1927), in a study on the storage of some perishable root crops, found that gabi was successfully stored in the dark for 92 days; ubi in the cellar for 92 days; yautia for 40 days in the cellar and tugui for 72 days in the cellar, cassava for 25 days in the cellar had the lowest percentage loss of 63.96%.

Table V. Yield of fresh roots, starch and percentage extraction as affected by age of harvesting in cassava.

Age of plants (months)	Av. yield per ha (tons)	Commercial starch per harvest (800 plants)	% Extraction
Seedling No. 2152		kg.	
10	23.6	254.4	11.48
11	28.3	255.3	11.28
12	31.1	255.8	10.29
13	37.5	324.0	10.80
14	41.8	333.0	9.96
Aipin Valenca			
10	19.6	167.0	10.65
11	20.9	171.7	10.27
12	23.4	188.0	10.04
13	23.7	178.0	9.39
14	24.0	170.0	8.85

Roxas and Manio (1921) determined the hydrolysis of cassava on different conditions and its fermentation to alcohol by different yeast preparations. They suggested that for every 100 kg of cassava flour, use 50 litres of acid solution containing 1 litre sulphuric acid (sp. gr. 1.84) hydrolized under pressure at 120°C (15 lb. per sq. inch) for 2.5 hours. Then neutralized it with 2 litres of ammonium hydroxide (sp. gr. 0.9), and dilute it to 600 litres plus 6 litres of yeast prepared by Wolhvent process. Distil the fermented liquid after the second day but not later than the third day.

They also attempted to extract starch from cassava. This method consisted simply of grinding the peeled cassava roots without water and drying in the sun or with the aid of artificial heat to a moisture content of 15%. Their results are shown below:

Test No.	Wt. of roots (kg)	Already starch (kg)	% extraction
1	24.95	5.8	23.3
2	148.00	36.24	24.2

The chemical composition of cassava is of interest to the planter, the starch processors and consumers. Adriano, et al. (1932) gave the proximate analysis of different varieties of cassava at the U.P. College of Agriculture. They used Mandioca Sao Pedro Preto, Mandioca Brtiorao, Aipin Valenca, Aipin Mangi, Kapo White and Rough Intermediate. The results are shown in Table VI.

Table VI. Proximate chemical analysis of cassava roots (After Adriano, et al, 1932)

Composition	Percentage
Edible portion	81.40
Moisture	63.80
Ash	1.44
Proteins	0.96
Fats, ether extract	0.26
HCN	0.02
Crude fiber	0.85
Starch	27.65
Other N.F.E	5.04
Calorific value/kg	1,403.00

Cedillo (1952) studied the possibility of preparing "landang" or cassava rice from the fresh roots. He found that "landang" compares favorably with corn and rice as to food constituents and calorific value. Although rice and corn contain more proteins (Table VII), "landang" has a greater amount of carbohydrates from the nutritive point of view. "Landang" can very well become a good substitute of corn or rice during hard times.

Table VII. Food value of "landang" as compared with corn and rice

Item	"Landang" %	Yellow Corn (Air-dry) %	Rice (Lowland) %
Moisture	14.2	15.88	11.39
Crude fat (ether extract)	0.26	4.47	1.10
Crude proteins	2.41	8.90	8.35
Carbohydrates	80.79	67.28	76.74
Crude fibers	1.68	2.86	0.92
Ash	0.65	2.61	1.50
Cal. value per 100 grams	335.00	353.91	359.09

RESEARCH ON SWEET POTATO

Sweet potato is the most important root crop in the Philippines. It may yet become one of our important industrial crops. Many varieties are grown and they vary in yield and quality. It is necessary, therefore, that yield trials be conducted to discover the best varieties.

Variety test

Cadiz (1944) found that Centennial, Phila, Seedling 47, BNAS 51 and Batanes were the promising varieties as a result of the yield trial at U.P. College of Agriculture. Previous to this were such varieties as Samar Big Yellow, Kadali, Tamisang Puti and Kabelang Puti (Alcantara, 1946; Zamora, 1947, Gapuz and Zamora, 1949, Calma and Panungbatan, 1950).

Propagation

The most common practice of propagating sweet potato in the Philippines is the vine cuttings. Some claimed that the highest yield is obtained when cuttings are planted in a slanting position. Others believed that either the bent or twisted one gives the best results.

Tenebro (1935) compared the positions of planting on two varieties and found that the bent position was the best in the production of roots (Table VIII). The others are slanting and twisted positions.

Table VIII. Yield of vines and roots of sweet potatoes as influenced by positions of planting

Position	Vines kg/ha	Roots kg/ha
1. Slanting	40,224	19,144
2. Bent	53,556	22,752
3. Twisted	50,060	16,756

The Philippines farmers used 'camote' cuttings from different portions of the vine for planting. In some cases cuttings from sprouting tubers were used. Roque (1924) conducted an experiment to find out the relation between growth and yield of the plants grown from different cuttings. He observed that the tip cuttings gave the faster growth and the higher yield than the basal cuttings.

Intercropping and topping

Lawas (1947) tried to intercrop corn with sweet potato. He stated that the stand of corn was affected when sweet potato was planted at the same time with the former in the row or between hills. However, if sweet potato was not planted until after corn had been hilled up, the latter was not affected at all (Table IX).

Table IX. Yield of corn as influenced by intercropping with sweet potato

Treatment	Sweet Potato	Marketable ears	Non-marketable ears
Ordinary Upland Field			
1. Corn alone	—	2355.64	2855.81
2. Intercropped between the hills of corn	363.86	2067.79	3473.02
3. Intercropped between the rows of corn	343.08	1592.60	2558.40
Bulldozed Field			
1. Corn alone	—	2319.33	5202.12
2. Intercropped between the hills of corn	1797.09	1677.51	3770.04

Morales (1956) determined the effect of topping on root yield of sweet potato. He found that severely topped plants (all shoots acceptable for greens were removed) gave lower yield than the moderately topped (approximately one-half of the shoot acceptable for greens was removed). This was due to the reduction of the leaf area for the manufacture of plant food.

Fertilization

Lantican and Soriano (1961) reported that the yield of roots, leaves and vines increased with the rate of nitrogen applied. The highest amount of potassium increased the vegetative growth but did not increase the yield of roots. The response to the minor elements was inconsistent and phosphorus gave no response. The combinations of 100-90-90 and 100-90-0 were consistently the best for root yield; 100-90-90 and 50-90-180 for growth of leaves and vines (Table X).

Table X. Yield of roots and vines in tons per hectare of sweet potato in two seasons of tests

Treatment	Storage roots		Vine	
	Dry season	Wet season	Dry season	Wet season
N-P-K	1956	1957	1956	1957
0-90-0	4.98	11.20	1.87	1.71
50-90-0	5.75	12.93	1.97	1.68
100-90-0	8.78	15.04	1.64	2.00
0-90-0	6.83	12.19	1.87	1.98
50-90-90	5.13	11.38	2.30	2.23
100-90-90	9.75	16.80	3.07	3.51
50-0-90	6.62	13.32	2.21	2.34
50-90-90	6.05	14.94	2.05	2.36
50-90-180	6.48	13.08	3.23	3.04

Cadiz and Abhigay (1964) found that the application of fertilizer at the rate of 100-90-100 kilos of N-P-K, respectively, per hectare generally promotes vigor and production of uniform roots. Closer spacing yielded more than wider spacing but better vigor and more uniform roots were obtained in wider spacing. In general, 20 cm. spacing fertilized at the rate of 100-0-0 and 200-0-0 was shown to be the best combination of greater and heavier roots.

Cadiz and Hermano (1964) determined the effect of starter solution and age of cuttings on the recovery and yield performance of three varieties of sweet potato, namely Phila, Batanes and Seedling 47. They noted that delaying planting of cuttings for a day or two seems to favor better recovery. Generally the use of starter solution (5 lbs. of 12-24-12 fertilizer for every 50 gal. of water) promotes greater survival and total yield, better vigor, better yield of marketable roots.

OTHER ROOT CROPS

Taro, or gabi, yam or ubi and arrowroot are other sources of food. Research involving cultural practices with these crops has been rather limited. A few of them are herewith presented.

Pagtirigan (1950) opined that gabi required 500 to 600 kg. per hectare of a mixture of 6% N, 6% P_2O_5 and 12% K_2O for a fond yield of corms.

Banaag (1958) determined the effects of individual and combined application of N, P, and K on the yield of corms and vegetative parts. The highest level of N (150 kg/ha) mixed with 90 kg of P and 90 kg of K increased the yield of corms and vegetative parts. Coligado (1964) on the other hand, recommended the application of 180, 90, and 90 kg. per hectare of N, P, and K respectively.

An experiment is in progress on the effect of poles in the yield of ubi or yam at varying hill spacing. This was conceived because of the general practice of the farmers to use support for this crop without considering the distance between plants.

There is no distinct variety of arrowroot in the Philippines, as the plant is grown only in semi-cultivated condition.

UTILIZATION OF ROOT CROPS FOR FORAGE

Chemical analysis represents the starting point determining the nutritive value of feeds. Mendiola (1931) in an article on the growing of cassava in the College of Agriculture, U. P., gave the quality of roots of the different varieties of cassava found in the Philippines (Table XI).

Although roots cannot replace legume hay in stock feeding, they can be used as a substitute for a considerable part of grain customarily fed to swine or poultry. Feeding trials conducted at the College of Agriculture have shown that cassava may be utilized to great advantage by feeding it to hogs. There are however, some varieties grown in the Philippines, some of which are more or less poisonous. The substitution of one feed for another is an important and ever present factor in swine feeding. Some feeds become scarce, others become unavailable. Feed prices change from time to time.

Alba (1937) studied a number of casssava varieties for hog feeding purposes. He used four varieties and observed that all varieties did not produce fatal effect on pigs fed with them (Table XII). From the point of view of the rate of gain, the replacement of from 5-15% of the basic concentrate ration by cassava in proportion of 3 parts of cassava roots to be one part of concentrate proved to be most practical and economical.

Aipin Valenca was consistently superior to those from other lots. It is not poisonous and with good flavor and not fibrous (Mendiola, 1931). The replacement of 5% of concentrate ration by cassava roots is practical in a dry-lot system of feeding.

Table XI Quality and flavor of different varieties of cassava

Variety	Quality	Flavor
Mandioca Sao Pedro Preto*	VP	not edible
Mandioca Lapiento*	NP	fair
Mandioca Bastiato	NP	fair
Mandioca Itaploca	NP	good
Mandioca Crioulinha	P	not edible
Aipin Valenca*	NP	good
Aipin Mangi*	NP	very good
Aipin Trapecuana	NP	good
Aipin Manteiga*	NP	good
Cuspare Singkong Manis	NP	very good
Kapo White	NP	good
Kapo Colorado	NP	fair
Rough Intermediate	NP	good
White Smooth Intermediate	NP	good

VP — very poisonous
NP — not poisonous
P — poisonous
* — included in the present collection of cassava varieties of FCD, Department of Agronomy, U.P.C.A.

Table XII. Feeding value of cassava tubers on pigs

Items	Lot I (Control)	Lot II (5% Mandioca Tapicuro)	Lot III (5% Aipin Valenca)	Lot IV (5% Mandioca Itaparica)	Lot V (% Mandioca Basiorao)
Average initial weight (kg.)	7.12	7.16	7.20	7.16	7.08
Average final weight (kg.)	25.28	22.68	26.04	23.36	25.80
Average daily gain per pig	0.26	0.22	0.27	0.23	0.27
% of ration to live weight	3.14	3.04	2.96	2.96	2.91
Feeds consumed per kg gain	2.80	2.95	2.62	2.79	2.56

Mondonedo (1928) compared the feeding value of corn and cassava for hogs. One lot of 8-month old pigs was fed with a ration containing 20% corn, and the other lot was replaced by twice its weight of peeled, chopped raw cassava. The cassava lot made an average daily gain per pig of 0.40 kg. corn lot, 0.36 kg. The former required 0.44 kg more feed to make a kg gain than the latter.

Mondonedo and Bayan (1927) fed for 70 days two lots of 3-month old pigs on 'camote' pasture, one on a ration containing 30% corn and the other on the same ration with corn replaced by cassava on the basis of one part corn to 2 parts cassava in cooked form. In producing gain, ground corn proved to be slightly better than either the whole corn or 3 parts cooked cassava. Three parts of peeled cooked cassava, which is equivalent to 2 parts of raw cassava had approximately the same feeding as one part flint corn grain.

Mondonedo and Alonte (1931) reported that cassava or sweet potato is a good substitute for corn in the ration of pigs when fed in dry lot. Two parts by weight of cassava or sweet potato are about 87% as one part corn in feeding value and 2 parts 'pongapong' are equivalent to 75%. In other words 2.3 parts of cassava or sweet potato and 2.67 parts of 'pongapong' are equivalent to 1 part corn.

Penu'iar (1940) studied the value of cassava refuse meal and rice bran as feeds for growing and fattening pigs. In rate of gain, cassava refuse was only 52% efficient when substituted for rice grain in the College standard ration during the 210-day feeding period. As to the amount of feed required to make a kilogram gain, cassava refuse meal was 61% efficient as compared with rice bran.

Gaplek meal is a good substitute for corn in the ration for growing and fattening pigs (Asien, 1941). He compared gaplek meal and corn as basal feed for growing and fattening pigs. He observed that with the amount of feed required for a given unit of gain as the basis of comparison, gaplek meal was 90% as efficient as corn for the 210-day feeding test (Table XIII).

Table XIII. Feeding value of gaplek as a substitute for corn in pigs

Items	Lot I	Lot II
Average initial weight per pig	17.71 kg.	12.71 kg.
Average final weight per pig	75.29 kg.	70.49 kg.
Average daily gain in weight	0.30 kg.	0.27 kg.
Feed consumed per kg. gain	5.39 kg.	5.68 kg.

Tabayoyong (1935) used cassava refuse meal in the ration for growing chicks. The rice bran fed chicks grew faster than those fed with cassava refuse meal. Those fed with a combination of cassava and rice bran were intermediate in size between those fed with rice bran and cassava with a tendency to approach those of rice bran. The cassava refuse meal fed chicks had the slightest percentage of mortality 59.4% those fed with rice bran, 41.5% and those with combination, 42.5%.

Some years ago it was considered nearly essential to supply succulent feeds to livestock to secure maximum growth from any rations. Some of these are leaves of sweet potato, 'ipil-ipil', young shoots of Centrosema and Calopogonium. Swine can be raised on concentrates alone, but experiments have shown that through the use of suitable forage and pasture crops pork may be produced at a much lower cost than when pigs are maintained in dry lots on expensive concentrates.

Rodriguez and Kohmson (1927) observed that pigs on pasture did considerably better when given 'camote' vines in the form of soilage in addition to the concentrate alone.

When rapid growth and development is the object sought, full feeding with dry ration with access to a good pasture like sweet potato is a better practice than limiting the ration (Suriano, 1932). Sweet potato has a marked superiority over Calopogonium as pasture for hogs, full fed or on limited ration.

Dingayan and Fronda (1950) compared Centrosema, 'ipil-ipil' and sweet potato vines as green feed to chicks. Either finely cut green leaves and young shoots of 'ipil-ipil' and Centrosema are much better than sweet potato leaves and young shoots as green feed for growing chicks (Table XIV).

There were no significant differences in digestion coefficients for organic matter, fat and protein in sweet potato tubers and vines, cassava roots and green papaya fruits by different breeds of pigs. Philippine native pigs had the highest digestion coefficient (Zarate, 1956).

Table XIV. The average proximate analysis of three green feeds

Constituent	Ipil-ipil	Centrosema	Sweet potato
Moisture	74.89	74.63	89.63
Crude Protein	0.36	0.72	0.24
Crude fats	2.77	2.02	0.45
Carbohydrates	17.69	15.23	6.39
Crude Fibre	2.25	5.86	1.48
Ash	2.04	2.04	1.81
Calorific value/100 grams	97.00	80.00	31.00

Castillo, *et al.* (1964) confirmed that corn can be entirely replaced by either camote or cassava silage in the swine ration. Their test showed that when camote or cassava silage replaced corn in growing and fattening swine ration, the gain in weight is the same as in corn (Table XV).

Table XV. Proximate analysis of camote and cassava tuber silage

Silage	Dry Matter %	Ash %	Crude Protein %	Proximate Ether extract %	Crude fiber %	NFE %	HCN mg/100 grams
Camote tuber:							
before ensiling	30.88	1.24	0.50	0.30	1.05	27.79	—
1st sampling	38.03	1.46	0.76	0.39	1.47	33.93	—
2nd sampling	30.03	1.57	0.82	0.21	1.49	25.94	—
3rd sampling	39.17	1.51	0.74	0.20	1.57	35.15	-
Cassava tuber:							
before ensiling	36.07	1.16	0.98	0.99	1.28	31.66	10.71
1st sampling	43.45	1.88	0.61	0.30	2.10	38.56	9.72
2nd sampling	46.46	2.08	0.82	0.19	2.78	40.59	9.72
3rd sampling	41.19	1.57	0.68	0.23	1.57	37.14	9.40

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RESEARCH ON ROOT CROPS BY IRAT IN AFRICA AND MADAGASCAR

— *by* —

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Root crops play an important part in feeding some African and Malagasy populations. In several areas root crops are still used as a basic foodstuff: manioc in the forest areas of West Africa and of Equatorial Africa, yam in the areas of wet tropical climate along the edge of the dense forests of West Africa, and taros in West Cameroon. Nevertheless, these crops are also grown on areas lying beyond these narrow limits particularly those species which are adaptable to a wide range of environments. Being nowhere a staple food, sweet potato is cultivated almost throughout the African continent and in Madagascar. Taro crops are found in the wettest zones of West Africa, in most countries of Equatorial Africa and in Madagascar except in the cold areas of high altitude. Yam cultivation is widespread in Equatorial Africa. Lastly, manioc is an important industrial crop in Madagascar and in Togo. It also has general use as a supplementary food and is particularly valuable as a security against disastrous cereal harvests. In this contest, cassava cultivation is spreading even in the relatively dry areas of Africa.

Investigations on root crops are being carried out by IRAT in Madagascar, Senegal, Dahomey, Niger, Gabon and Central African Republic; their importance varies according to the species and the countries. The main objectives and results of these studies will be described below.

MADAGASCAR

The country has a wide range of ecological zones. This diversity is due to the different degree of fertility of soils depending on their pedological origin and on differences in climate : for instance, a wet tropical climate on the Eastern Coast, a dry tropical climate on the Western Coast with arid areas in the South and a high elevation tropical climate in the interior of the country.

Here IRAT is carrying out intensive investigations on manioc and less important studies on the sweet potato. The first studies were initiated about 30 years ago, with a special aim to improve the industrial crops devoted to starch and tapioca production.

At the beginning they were primarily concerned with mosaic control. This virus disease had recently spread in the Island and had reduced yield considerably. Control was attempted by breeding for resistance. The criteria for selection were :

— the resistance to mosaic which was evaluated by visual symptoms forming five classes of susceptibility.

— yield capacity according to the useful starch production in relation to the total weight of dry matter in the plant.

— the resistance to some rots, particularly to physiological rots occurring in soils which were periodically water logged.

The method used was the artificial hybridization between clones having some required characters. The parents originally used were selected from a world collection, the most interesting introductions originating from Reunion, Java and Malaysa. The use of the factors of vigour and of resistance to mosaic of closely-related species, particularly *M. glosivii*, by inter-specific cross was also attempted.

Subsequently the parents of the new hybrids were selected among the old hybrids with more desirable characters. About fifteen clones either resistant or tolerant to mosaic, highly productive and adapted to various soil types were thus developed. Observations on mosaic have shown that a clone resistance is not always final, perhaps because of some evolution of the physiological strains of virus.

The accumulation of the cyanogenetic glucoside content of roots was studied. This revealed higher contents in the roots during the first year than during the second year with a maximum in the dry season and minima in the wet season for both years.

Studies on mineral nutrition and fertilization have also been performed. The high nitrogen and potash requirements of plants were established and a test to estimate potash requirements by analysing the phelloderm was developed. There is a positive correlation between the potash content of phelloderm and root and starch yield. Organic matter plays an important part in high yields. When farmyard manure was lacking, *Mucuna*, a green manure proved to be very efficient.

Lastly, technological studies particularly on the improvements required by the various manioc mills in Madagascar have been performed. With respect to industrial manioc great progress has been achieved. Since 1960, research work has been particularly directed towards the improvement of variety and of the cropping systems used in the small farms. In the country this product is principally used as feed supply but also as a supplementary food in human diet particularly in the Southern part of the Island where the main food crops are still subjected to accridien attacks.

In this way, the work on genetic improvement carried out according to the same methods are still aimed to obtain high yields, mosaic resistance but also a low cyanhydric acid content of roots.

Very interesting varieties are now available and among them H41, H46, H49, H44, for starch production; H53, H45, H52, H47 for direct consumption, H53, H52 for drying and H54 a very interesting multipurpose variety which is in addition extremely plastic. The present yields from the trials are of about 40 tons/ha or more.

A study of the different drying methods which could be used in family farms for tubers cut up into pieces (cossettes) showed that complete drying can be obtained with 70 hours of sun exposure on reed racks provided that elementary precautions were taken.

Several trials largely decentralized throughout the island are being conducted on variety improvement, on the adaptation of cultural practices to family farming and on fertilizer use.

Sweet potato

Work on this species is very limited. The behaviour of local varieties and of some improved varieties introduced from the United States has been studied. Some local varieties show a very high potential production often superior to that of the introduced varieties. Trials on fertilizer use have generally indicated a favourable effect of nitrogen.

SENEGAL

The ecological conditions of Senegal, unlike those of Madagascar, are relatively homogenous; most soils are light and rather poor, and the variable element is climate which progressively changes from South, where rainfall rises to 1200 mm, to North where rainfall is of about 350 mm, but in any case rainfall is concentrated over one relatively short season.

The majority of the population is concentrated in the central-west area characterised by a rainfall ranging from 800 to 500 mm. The production of this area is essentially groundnut and cereals (millet and sorghum) the latter being in inadequate amounts to meet the food requirements of people.

In this country IRAT is carrying out very extensive research work aimed at replacing the present primitive cropping system with a system of family farming which is intensive, and carried on at an increased level of soil fertility, with diversified production, and the use of a rational rotation incorporating mixed farming (draft animal and beef cattle).

Here, manioc is studied with regard to crop diversification; without doubt it will keep on being used as a supplementary food. Some increased use is also expected as a supply of animal feed, as well as for some local industrial markets (bread, biscuit).

The work consists of clone selection on populations from seeds. Since climatic conditions are unfavourable for the mosaic vector in Senegal the character of resistance to this virus disease is not taken into account. Some highly productive clones have been selected; a relationship between the regrowth ability of cuttings and the productivity of clones has also been noted.

As regards fertilizer use the interest of nitrogen-potash fertilizers and the ineffectiveness of phosphorus despite of the serious phosphorus deficiency of soils has been pointed out.

As for cultural practices it has been determined that the best plant rate was between 8,000 and 10,000 cuttings per hectare planted in rows 1, 5, to 2 m apart

Studies on the best harvest time according to plant are and of the most suitable dates of planting are now in progress. Simple methods of drying tuber roots cut up into small pieces (cossettes) which can be used within the framework of a family farm are also studied.

DAHOMEY

The country is characterized by an equatorial climate with two rainy seasons in South and a Tropical climate with one rainy season in North. Everywhere total rainfall ranges from 1000–1200 mm a year.

Manioc plays an important part in feeding the population particularly in the South and yam plays an almost equal part in the Central and Northern areas of the country.

Work on root crops has not yet been very much developed because precedence has been given to studies on cereals, particularly maize, and to the studies related to the improvement of cropping systems : the position of crops in the rotation, the improvement of fertility by fertilizer use and the study of fallows, green manures and fodder crops.

Manioc

The work concerning manioc mainly consists of developing very sweet varieties being also highly productive and resistant to mosaic. These objectives are tried to be obtained by clone selection on progenies from seeds and from a polyclonal field in which individual plants have been selected among the local manioc plants the least injured by mosaic. A method which consists of introducing into a valuable and highly productive variety the genes of mosaic resistance present another local variety by hybridization and back-cross has run against the difficulty of obtaining synchronous flowering for the two parents.

Yam

Concerning this species local varieties belonging particularly to *D. cayenensis*, *D. rotundata* and *D. alata* species have been collected. This collection gives rise to observations particularly about productivity. Each variety, indeed, is adapted to particular uses; early or late harvest, good storage qualities, or use on the occasion of some traditional ceremonies. Any improvement programme should essentially take these various factors into account.

Independently of the variety problem which has been hardly tackled it has been shown that plantations with 8000 mounds/ha were the most favourable under the conditions of traditional cultivation on mounds. Till now the results from fertilization trials are contradictory. Lastly, experiments aimed to define yam position in rotation are being carried out.

OTHER AFRICAN COUNTRIES

In Niger where conditions are almost similar to those of Senegal, the manioc clones having been developed in this country are tested under various ecological conditions.

In Gabon, a wet and forest country, manioc and sweet potato varieties have been introduced. Manioc introductions come essentially from Madagascar because of the mosaic disease present in the country and of the interest of possessing already resistant clones. Sweet potato introductions come from the United States.

In Central African Republic works are limited at present to the study of a manioc collection of local varieties and to trials on harvest time in which the most favourable vegetative period of the best clones is tried to be determined.

NOTES ON SWEET POTATO RESEARCH IN WEST NEW GUINEA (WEST IRIAN)

— *by* —

J. Roinard

In most of the Papuan communities of West New Guinea (West Irian), like on many other islands in the Pacific, the food intake is largely dependent on a single staple food, namely sago, taro or sweet potato.

The sweet potato is the crop of the high valleys in the central part of the territory, where almost half of the population lives. These people, whose existence was not known until twenty or thirty years ago and who since their first contact with explorers and governmental administrators hardly have been influenced by modern civilization, apply a remarkably accomplished agricultural system. The particular areas are very densely populated and suitable land is scarce. Consequently, shifting cultivation is a luxury the highland Papuans from time immemorial have not been able to afford. They developed instead agricultural methods permitting almost permanent soil utilization. It is their practice to grow sweet potato in checker-board gardens, which generally consist of more or less square beds, often the size of as little as 2 or 3 m2., and wide and deep drainage ditches surrounding the beds. After each harvest and before planting the next crop the ditches are deepened considerably. All mud, plant waste and other dirt thus excavated is spread over the beds, thereby covering and conserving the organic material left over from the previous crop. Apparently as a result of this routine, the soil is kept in a sufficiently fertile condition to produce time after time satisfactory yields.

In every respect the physical well-being of the highland Papuans depends on the sweet potato, which accounts for nearly one hundred percent of their diet. In addition they consume negligible quantities of sugarcane, some wild herbs and pork, the latter only when on the occasion of the sporadically occurring ritual festivities pigs are slaughtered.

Of course, this unbalanced diet — although, as readily is admitted, the people concerned have survived on it for many generations — was a matter of great concern to physicians and nutritionists. They detected various deficiencies, the most serious of these being a general prevalence of protein malnutrition.

Steps to counterbalance the protein deficiency were considered necessary. But how should this problem be tackled? It would certainly not be a practical and lasting solution to import protein-rich food from elsewhere for distribution among the numerous highland communities, which generally neither know money nor are in a position to earn it and due to the absence of roads and navigable waterways are completely isolated from the coastal areas. Therefore, any realistic attempt to improve the diet would have to be based on measures within reach of the people concerned, viz., raising more farm animals and fish, growing crops containing much protein and increasing the protein content of the traditional food crop.

The first and second approach are both beyond the scope of this paper. Suffice it to say here that the agricultural officers responsible for carrying these measures into effect encountered almost insurmountable difficulties, mainly because of the mountain dwellers' fervent dislike for everything which is new to them, including new food stuffs.

The present paper deals with research predominantly aimed at improving the nutritional value of the sweet potato, which was carried out by the Agricultural Research Station, Manokwari, in co-operation with the Department of Tropical Crops of the State of Agricultural University, Wageningen, The Royal Tropical Institute, Amsterdam and The Central Institute for Food Research, Utrecht. Investigations began in 1959 and lasted until 1963, when the work had to be broken off in consequence of the transfer of West New Guinea (West Irian) by the Netherlands to Indonesia. Part of the findings have been published in scientific journals. A great deal of the results, however was still hidden in internal reports and notes. It seemed useful to recapitulate the whole of the work in one paper to be presented to the First International Symposium on Tropical Root Crops.

CHEMICAL COMPOSITION OF SWEET POTATO TUBERS

Introductory Remarks

In the literature on the subject widely diverging percentages for the various constituents of sweet potato tubers occur. To a certain degree this lack of uniformity may be due to genotypical differences between the clones concerned, but it is very likely that also other factors play a role, such as methods of sampling, treatment of the samples, age of the crop and environmental conditions during the growing period.

Consequently, most of the analysis performed as part of the present study were not only to provide data on the chemical composition of tubers of different clones, but at the same time had to turn out information on the import of these other factors.

Not until 1962, a branch of the Agricultural Research Station was established in the highland. As a result during the greater part of the research period most of the field work had to be carried out at the main station, in the beginning at Hollandia and later at Manokwari (both lowland). This did not present serious difficulties, since the sweet potato grows very well at low altitudes. Moreover, a large collection of clones from the coastal area as well as the high valleys and from abroad was already available at the main station.

A more detailed presentation of part of the work discussed below is given in Oomen et al (1961) and Ruinard (1960).

Sampling and treatment of the samples

All chemical analysis had to be performed in The Netherlands, mainly at the Royal Tropical Institute and partly at the Central Institute for Food Research.

Preliminary laboratory work had shown that for chemical analysis Samples of 1kg fresh weight each were adequate. It was also found that such Samples provided they consisted of big and small tubers selected at random from the whole lot, were large enough to be sufficiently representative for the ample quantities of tubers obtained from sizable plots.

Table 1. Chemical composition of the tubers of various high-yielding clones

Contents (in percentages of fresh weight)	Boalodap	Kadanga red	Kadanga white	Papeda	[illegible]
water	65.[illegible]	71.2	69.9	[illegible]	71.2
fibre	0.86	1.[illegible]	1.2[illegible]	4.82	1.02
starch	21.4	19.[illegible]	20.9	13.7	[illegible]
sugar	2.9	4.0	1.1	[illegible]	[illegible]
crude protein	0.85	[illegible]	[illegible]	[illegible]	0.72
real protein	0.48	[illegible]	0.6[illegible]	0.64	0.59
ash - total	0.92	[illegible]	0.8[illegible]	0.86	0.83
K	0.[illegible]9	0.41	0.3[illegible]	0.18	0.39
P	0.052	0.044	0.049	0.044	0.037
Mg	0.023	0.019	0.019	0.016	0.015
Ca	0.039	0.030	0.031	0.029	0.021
Na	0.0013	0.0009	0.0009	0.0014	0.0014
Real/crude protein	0.4[illegible]	0.5[illegible]	0.85	0.78	0.84
Flesh colour	(white)			(light yellow)	
Origin of the clones	(Wissel lakes area (highlands))				
Soil where grown	(clay)				
Age when harvested	([illegible] months)				

Genyem 1	Lampon 2	Pain Selatan	Logikiyua 5	Enny Bud	21—51	21—82	21—123
70.5	75.4	72.1	74.1	75.0	69.1	73.2	76.9
1.37	0.94	1.08	1.23	1.06	1.14	1.09	1.04
17.8	15.9	16.8	12.2	11.2	18.9	13.6	12.[illegible]
9.1	3.5	4.7	6.5	4.6	4.6	4.2	4.8
1.43	2.45	2.27	2.12	2.05	2.20	2.18	1.75
1.07	1.65	1.89	1.45	1.52	1.67	1.51	1.11
0.85	0.86	0.89	[illegible]	0.42	0.79	0.86	0.75
0.40	0.34	0.37	0.40	0.30	0.31	0.31	0.29
0.060	0.082	0.059	0.064	0.074	0.090	0.087	0.068
0.028	0.044	0.040	0.055	0.054	0.050	0.045	0.049
0.026	0.054	0.076	0.061	0.086	0.019	0.021	0.028
0.0015	0.0011	0.0014	0.0013	0.0015	0.0015	0.0013	0.0012
0.75	0.80	0.16	0.64	0.84	0.74	0.59	0.64
pale purple		yellow			orange		
Hollandia (lowland)		Enarotali			U.S.A.		

Hollandia (lowland)

NG month

To economize on airfreight costs and to prevent deterioration during transport, immediately or at most a few days after being harvested (except in the storage experiment) all tubers were cut to slices not thicker than 5mm and subsequently dried at temperatures ranging from 35° to 45°C. The dry and crisp slices, containing not more than 10% moisture, were then packed in polythene bags and immediately shipped by air to the above-mentioned Institutes.

Constituents of various clones

To begin with the chemical composition of tubers from eight clones grown in the collection of the main station (lowland) and five clones grown in an experimental garden in the Wissel Lakes area (highland) was ascertained. All thirteen clones are relatively high-yielding. The first eight were grown at the same site and planted and harvested at the same date. This also applies to the second group of five clones The results are presented in Table I. The percentage starch was found by direct determination. Sugars were determined as glucose. Crude protein was found by means of the Kjeldahl method, real protein by precipitating first all protein compounds with $CuSO_4$ and NaOH followed by Kjeldahling the precipitate (both nitrogen contents thus determined were multiplied by 6,25 to obtain the percentages crude and real protein).

Table I confirms that the chemical composition of different clones may vary widely. Particularly striking were the differences in protein content. On the whole the clones grown in the lowland contained considerably more crude and real protein than those from the highland. However, in the former group the ratio real/crude protein was smaller than in the latter. There were also noticeable differences in the contents of starch and sugar, indicating that certain clones are much sweeter than others. The differences in the mineral compounds were generally less conspicuous.

Effect of ecological factors

Four clones native in the high valleys were grown at the same time in the Wissel Lakes area (highland) and at Manokwari (lowland). To rule out even the slightest chance of accidentally using impure planting material, all cuttings used for the two plantings had been raised in multiplication plots, one for each clone at each site, both planted with cuttings obtained in the highland from a single plant of the particular clone At both sites the crop was harvested when seven months old. Table II gives a resume of the results.

Two striking differences between the two sites stand out. The first concerns the protein content. The tubers grown in the Wissel Lakes area contained considerably more crude protein and also their real/crude protein ratio was noticeably higher, the net result being a real protein content approximately twice as high as in the tubers produced at Manokwari. Secondly, the lowland tubers contained roughly fifteen to twenty times as much sodium compared with the highland tubers.

Effect of storage

Immediately after harvesting a field trial with the clones Okinawa 1 and Louisiana 5 at Hollandia, from both clones three samples were taken. One

Table II. Effect of ecological factors; composition of the tubers of four clones grown in the Wissel Lakes area (at + 1700 m) and at Manokwari (+10 m)

Contents (in percentages of fresh weight)	Ieumeja Highland	Ieumeja Lowland	Nabedau Highland	Nabedau Lowland	Mogoudugu Highland	Mogoudugu Lowland	Bugaanota Highland	Bugaanota Lowland
water	64.7	67.8	69.0	69.1	69.9	72.3	73.8	69.9
fibre	0.92	1.06	0.93	0.99	0.96	0.89	0.86	1.23
starch	24.6	21.2	19.0	23.2	18.9	19.6	15.6	21.4
sugar	4.7	5.3	5.3	4.3	5.0	4.2	5.6	3.4
crude protein	1.06	0.53	1.36	0.96	0.78	0.32	0.90	0.66
real protein	0.95	0.47	1.15	0.71	0.66	0.22	0.81	0.39
ash – total	0.86	1.03	0.95	1.17	0.89	0.92	0.60	1.11
K	0.31	0.28	0.29	0.28	0.31	0.30	0.18	0.26
P	0.072	0.074	0.065	0.062	0.055	0.075	0.062	0.054
Mg	0.015	0.018	0.018	0.015	0.010	0.016	0.020	0.018
Ca	0.058	0.078	0.056	0.108	0.039	0.077	0.051	0.106
Na	0.0021	0.0335	0.0019	0.0337	0.0021	0.0170	0.0016	0.0352
Real/crude protein	0.90	0.89	0.85	0.74	0.85	0.62	0.90	0.59
Flesh colour	(.................. white ....)				(...light yellow ...)		(.....orange.....)	
Origin of the clones	(.......................... Wissel Lakes area (highland) ....)							
Age when harvested	(.......................... 7 months ....)							

sample of each clone as dried at once and directly sent to the Netherlands for analysis. The second sample was stored for half a month and third for one month, at a shady and wind-swept place, prior to being dried and shipped.

Storage for half a month caused many buds to swell and sprout. After having been stored for a month part of the shoots had even developed green leaves. As appears from Table III particularly during the first half month strong desiccation occurred, resulting in wrinkling and softening of the tubers. It is likely that the stored tubers in addition to moisture also lost dry matter. The composition of the dry matter, however, did not undergo great changes.

Effect of age when harvested

From plots planted with the clones Okinawa 2 and Unit 1 Porto Rico (Hollandia) samples were taken four, five and six months after planting, whereas plots planted with the clones Mogou and Buguamotta (Wissel Lakes area) were sampled when the crop was six, seven, eight and one-half and nine and one-half months old.

Table IV shows that as to the chemical composition it did not make any significant difference whether the tubers were harvested early or late. The contents of the various constituents remained practically unchanged

Carotene

From a nutritional point of view carotene is an important component of sweet potato tubers. However, since carotene present in stored vegetable material tends to disintegrate rapidly, particularly when exposed to relatively high temperatures, the above-mentioned dried samples were not suited for estimating the carotene content in fresh tubers. Instead, newly harvested tubers from a number of clones grown in the experimental garden at Manokwari were immediately sent by air to The Netherlands and analysed at once.

It is evident from Table V that the carotene content varied widely from clone to clone. In accordance with the results of similar investigations elsewhere, it was found that the tubers contained more carotene as the colour of the flesh was darker.

Discussion

The analysis described so far have revealed that the tubers of different clones grown at the same time in the same environment may differ considerably in their chemical composition, particularly as regards the contents of carbohydrates, protein and carotene. They have also shown that differences in environment may cause noticeable changes in the nutritional value of tubers of the same clone.

Some of the clones in the lowland collection were found to contain twice or three times as much real protein as polular highland clones grown in the Wissel Lakes area (Table I). On the other hand, however, highland clones growing in the lowland appeared to produce only half as much real protein per kg fresh tubers as in their original environment (Table II). This may indicate that in the highland conditions for protein formation are better than in the lowland. If this conclusion is correct, then it is not unlikely that the best clones from the

Table III. Effect of storage: composition of tubers of two clones grown at Hollandia (lowland) and harvested when 5½ months old (after drying directly shipped)

Contents (in percentages of dry matter)	Okinawa 1			Louisiana 5		
	Drying immediately after harvest	Drying ½ month after harvest	Drying 1 month after harvest	Drying immediately after harvest	Drying ½ month after harvest	Drying 1 month after harvest
fibre	4.4	3.4	3.7	3.9	3.9	3.8
starch	61.3	67.6	66.8	54.7	56.9	55.2
sugar	11.2	12.1	11.2	19.6	17.5	17.0
crude protein	4.2	4.0	3.8	5.3	5.2	5.8
real protein	3.9	3.6	3.2	4.6	4.6	5.0
ash	3.1	2.8	3.1	3.4	3.4	3.7
Real/crude protein	0.93	0.90	0.84	0.87	0.88	0.86
Dry matter as a percentage of the weight of the tubers (before drying began)	28.6	38.0	38.8	30.4	36.3	36.5
Flesh colour	(............ white ....)			(............ yellow ....)		
Origin of the clones	(.... Papua and New Guinea ....)			(............ U.S.A. ....)		

Table 20. Effect of age when harvested, composition of tubers of four clones [illegible]

	[illegible]			[illegible]		
	4	5	6	4	[illegible]	[illegible]
Contents (as percentage)	months	months	months	months	months	months
(% fresh weight)	2? 4	2? 6	?4.5	?4.5	?? [illegible]	[illegible]
[illegible]	?.97	0.6?	0.89	?.28	[illegible]	1.05
fibre	?1.8	1? 6	4.?	[illegible]	[illegible]	[illegible]
starch	[illegible]	? 9	4.?	?.?	[illegible]	[illegible]
sugar	1.77	1.99	1.?4	2.0?	?.75	1.87
crude protein	1.1?	?.05	0.9?	1.59	1.32	?.97
[illegible] protein	0.7?	0.72	0.?0	0.46	0.94	?.88
ash - total	0.95	?.29	0.?9	0.86	?.55	0.5?
K	0.04?	0.0?5	0.0??	0.05?	0.0?1	0.088
P	0.0?6	0.03?	0.0?5	0.0??	0.0?7	0.0?6
Mg	0.024	0.024	0.024	0.0?7	0.?44	0.034
Ca	0.0009	0.00??	0.00??	0.0008	0.0015	0.00??
Na	0.71	0.66	0.?1	0.76	0.?5	0.??
[illegible]		white				
Flesh colour						
Origin of the clones	[illegible]	[illegible]		[illegible]	[illegible]	
Site where grown	[illegible]	Papua and New Guinea		[illegible]	U.S.A.	
	[illegible]		[illegible]			

harvested 4, 5 and 6 months after planting (lowland) and [illegible] 6, 7, 8½ and 9½ months after planting (highland).

Wagol						Bugaanda [illegible]	
6 months	7 months	8½ months	9½ months	6 months	7 months	8½ months	9½ months
21.6	24.8	24.4	23.9	25.9	27.4	26.1	26.7
1.11	1.26	0.84	0.89	1.04	1.06	0.73	1.00
16.6	11.4	15.0	16.0	15.0	12.7	13.8	13.4
3.6	4.2	5.1	4.2	6.2	3.2	5.4	4.8
0.94	0.76	0.75	0.86	0.77	0.59	0.65	0.72
0.62	0.71	0.67	0.73	0.64	0.52	0.53	0.56
1.07	0.86	1.00	0.95	0.84	0.80	0.57	0.64
0.50	0.43	0.45	0.43	0.29	0.25	0.24	0.32
0.060	0.038	0.051	0.052	0.048	0.039	0.036	0.036
0.048	0.018	0.016	0.018	0.015	0.012	0.016	0.016
0.046	0.022	0.020	0.025	0.020	0.016	0.024	0.032
0.23	0.21	0.0010	0.0010	[illegible]	0.0011	0.0004	0.0005
0.87	0.91	0.85	0.65	0.82	0.88	0.82	0.78

Table V. Carotene contents of fresh tubers of various clones grown in the experimental garden at Manokwari

Clone	Flesh colour	Carotene content in mg per 100g dry matter
Okinawa1	white	0.65
Genjcan 2	yellow	0.78
Louisiana 5	yellow	0.93
Louisiana 3	yellow	1.31
Louisiana 2	yellow	1.69
Louisiana 4	yellow	1.86
Putri Selatan	yellow	4.00
Porto Rico	pink	7.85
Copperskin Goldrush	orange	14.65
Louisiana 6	dark pink	17.83
Early Port	orange	29.04
Unit 1 Porto Rico	orange	33.12

lowland collection when grown in the highland would make an even better figure with respect to the highland clones in their own environment than finds expression in Table I. However, that may be, the results obtained strongly supported the assumption that it would be possible to improve the protein nutrition of the highland communities by making available to them sweet potato clones containing much more protein in their tubers than the traditional ones.

Total ash contents and composition of the ash were fairly constant for the different clones and sites. However, in this respect there was one very suspicious exception, viz., that tubers produced at Manokwari contained fifteen to twenty times as much sodium as tubers from the Wissel Lakes area and Hollandia (Tables I, II and IV). This was clearly an environmental effect that may be the result of soil differences.

Root crops like sweet potato have not a clear-cut stage of maturity. In the lowland people start collecting tubers when the crop is only three to four months old and often harvesting is not completed until seven or eight months after planting. In the highland, where growth is not rapid, harvest usually begins and ends one or two months later. As far as their nutritional value is concerned, there are indications that it does not make much difference whether the tubers, within certain limits, are harvested early or late (Table IV).

It is not uncommon that tubers are stored for a short time before being consumed. Table III shows that under normal storage conditions during the first weeks the tubers may lose a great deal of moisture. The chemical composition of the dry matter, however, was hardly affected.

NUTRITIONAL VALUE OF THE LEAVES

In addition to tubers the highland people also consume leaves of young shoots. These young and tender leaves are frequently roasted and eaten together with the tubers. The question arose whether this amounts to a nutritious contribution to the diet.

Samples of tubers and approximately 30 cm long top shoots were harvested in Okinawa 2 and Genjem 2 plots at Manokwari when these plantings were three, four and five months old and immediately sent by air to The Netherlands for analysis. The results are summarized in Table VI (taken from Ruinard, 1961).

It is evident that the dry matter of the leaves contained on the average five to six times as much real protein as the dry matter of the tubers. As to carotene the ratio was even much more in favour of the leaves. Also the contents of minerals tended to be higher in the leaves than in the tubers.

It is true that these analyses were concerned with plants grown in the lowland, but there is no reason to expect that highland material would prove to be very different in this respect. Consequently it may with due reserve be concluded that young leaves are valuable source of important nutrients, particularly of protein and carotene, so that there is every reason to stimulate in the protein-deficient highland communities the consumption of such leaves.

IMPROVEMENT OF THE HIGHLAND CROP

As appears from the analyses described in Chapter 2, some of the lowland clones contained considerably higher protein percentages than the common highland types. Obviously, introduction of these clones into the highland valleys and, provided the yields are satisfactory, their large scale distribution among the local communities would seem to contribute much to elimination of the protein malnutrition. However, this direct approach was out of the question, owing to the occurrence in the lowland plantings of an unknown but apparently serious disease, that according to investigations carried out in The Netherlands is caused by a virus or complex of viruses. Badly affected plants show dwarfish growth and do not produce any tubers. Import of this disease into the highland could be disastrous. Selfing or mutual crossing of highland clones, in the hope that among the progeny individuals rich in protein would be found, did not offer good prospects either because of the low protein contents of the parental plants.

Consequently the only way of obtaining better clones for the highland was to bring in from elsewhere seed of protein-rich clones and to select in the plant populations raised from this seed individuals with high protein contents and other desirable characteristics. The seed could either be imported from breeding stations abroad or it could be produced in the lowland collection. As to the latter source, however, it would have to be demonstrated first that the virus disease present in these plantings is not conveyed by seed. Starting from those considerations a programme was designed, of which unfortunately only a small, introductory part was realized when the work had to be broken off in the first months of 1963. Van Rheenen (1963, 1964, 1965) reported on these investigations. The following paragraphs are a resume of his publications.

Flower formation of most clones in the lowland collection was scanty and thus insufficient for large-scale breeding work, so that preliminary attempts were made to stimulate flowering by artificial means. With three clones the effect of training the tendrils along vertical racks was studied. All three appeared to

Table VI. Chemical composition of tubers and leaves

Contents (in percentages of dry matter)	Clone 2					
	3 months old		4 months old		5 months old	
	tubers	leaves	tubers	leaves	tubers	leaves
fibre	3.1	[illegible]	2.8	[illegible]	[illegible]	[illegible]
starch	65.9	4.2	71.5	3.2	70.9	8.0
sugar	7.3	1.1	10.8	1.5	12.3	4.5
crude protein	5.1	30.8	4.4	30.4	6.8	32.1
real protein	4.1	25.8	4.5	[illegible]	4.5	27.3
ash (total)	3.4	[illegible]	3.4	8.5	2.9	10.1
K	1.39	3.37	1.15	2.78	0.95	[illegible]
P	0.15	0.42	0.20	[illegible]	0.22	0.39
Mg	0.08	0.30	0.04	[illegible]	0.04	0.19
Ca	0.24	1.00	0.26	[illegible]	0.15	[illegible]
Na	0.04	0.061	0.067	0.059	0.105	0.098
Real/crude protein	0.90	0.84	0.85	[illegible]	0.72	0.85
Carotene content, in mg per 100g dry matter	1.3	22.1	1.0	24.1	1.9	52.2
Dry matter as a percentage of the fresh weight of tubers and leaves	32.4	[illegible]	[illegible]	[illegible]	31.6	13.5
Flesh colour	yellow					
Origin of the clones	Hollandia ([illegible])					
Site where grown	[illegible]					

7 — leaf [illegible] of [illegible] clones, 3, 4 and 5 months after planting

[illegible] 2

3 months old		4 months old		5 months old	
tubers	leaves	tubers	leaves	tubers	leaves
5.4	[illegible]	3.1	[illegible]	2.5	[illegible]
68.7	10.1	[illegible]	4.4	[illegible]	[illegible]
6.1	9.2	10.0	1.4	10.8	3.2
8.0	11.7	6.7	[illegible]	6.2	34.0
4.8	30.5	4.1	[illegible]	5.9	26.1
3.8	[illegible]	1.1		2.4	[illegible]
[illegible]	[illegible]	1.22	[illegible]	0.62	[illegible]
[illegible]	0.46	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	0.04	[illegible]	[illegible]	[illegible]
0.30	0.75	[illegible]	[illegible]	0.14	[illegible]
[illegible]	[illegible]	0.006	0.049	0.030	[illegible]
0.80	[illegible]	0.56	[illegible]	[illegible]	[illegible]
[illegible]	62.0	[illegible]	[illegible]	[illegible]	65.0
[illegible]	15.5	[illegible]	[illegible]	31.6	11.4

Maize

Papua and New Guinea

Mandobo lowland

Table VII. Rotation experiment: tuber and groundnut yields in four successive plantings that were planted and harvested on the dates indicated

No. of planting	Treatments A: continuously sweet potatoes without application of fertilisers	B: continuously sweet potatoes from 2nd planting 60 kg P_2O_5 per ha	C: sweet potatoes alternating with weed fallow	D: sweet potatoes alternating with Crotalaria	E: sweet potatoes alternating with groundnuts
1st	sweet potatoes 1/10/60 - 22/2/61 7,650 kg/ha	sweet potatoes 1/10/60 - 22/2/61 6,840 kg/ha	sweet potatoes 1/10/60 - 22/2/61 6,280 kg/ha	sweet potatoes 1/10/60 - 22/2/61 7,670 kg/ha	sweet potatoes 1/10/60 - 22/2/61 7,650 kg/ha
2nd	sweet potatoes 2/5/61 - 21/9/61 4,930 kg/ha	sweet potatoes 2/5/61 - 21/9/61 5,440 kg/ha	weed fallow	Crotalaria	groundnuts 3/5/61 - 30/8/61 1,120 kg/ha
3rd	sweet potatoes 23/11/61 - 24/4/62 1,280 kg/ha	sweet potatoes 23/11/61 - 24/4/62 1,440 kg/ha	sweet potatoes 23/11/61 - 24/4/62 1,080 kg/ha	sweet potatoes 23/11/61 - 24/4/62 1,050 kg/ha	sweet potatoes 23/11/61 - 24/4/62 1,610 kg/ha
4th	sweet potatoes 30/5/62 - 17/10/62 3,680 kg/ha	sweet potatoes 30/5/62 - 17/10/62 5,060 kg/ha	weed fallow	Crotalaria	groundnuts 30/5/62 - 25/9/62 1,430 kg/ha

produce more flowers. Also grafting on other *Ipomoea* species followed by training the plants along vertical racks, tried with two clones, was sometimes beneficial. Mutilating the plants by removing a wedge of tissue half-way across the main stem just above the root collar and training also in this case the tendrils along vertical racks, was for one of the two clones tested favourable but did not make any difference for the other. In order to give an idea of the quantitative results, it may be mentioned that the clone Louisiana 3 developed during its flowering period when growing in the ordinary way per plant on the average 1 flower in 100 days, when trained along racks 1 flower in 20 days, when grafted on *Ipomoea congesta* R. Br. (the best one of the stocks tried) 1 flower in 8 days and when incised also 1 flower in 8 days. Two more methods were tested, viz., fertilizing the plants heavily and reducing the daylight period to 8½ hours, both with one clone. The former was virtually ineffective; the latter reduced flowering to zero.

Natural fruit setting in the lowland collection was often sporadic but sometimes moderate (up to 25% of all flowers under observation). Fruit setting after artificial cross-pollination was usually good (up to 50% of the flowers pollinated); in a few instances, however, the percentage success was zero, this apparently being due to cross-incompatibility between the parental clones concerned. Artificial self-pollination proved unsuccessful in most of the clones tested.

Under natural conditions sweet potato seed often germinate very slowly whereas the germination percentage is low. Various experiments were conducted to improve this. Scarification near the top or the hilum yielded satisfactory results, but better still was immersion of the seeds in concentrated sulphuric acid for ten or twenty minutes followed by rinsing them thoroughly in clean water. In one case the latter treatment raised the percentage germination after one week as compared to the check from 10 to 70% and in another from 20 to 90%. Immersion of the seeds for 2 minutes in boiling water killed the embryos. Placing the seed in a little water of 100°C and allowing it to cool down to room temperature was not successful either, though this treatment did not kill the seed.

The breeding and selecting programme proper was only in its exploratory phase when the work had to be broken off. Yet some methods and findings seem worth mentioning. In the lowland collection parents were chosen on the basis of their yield, tuber shape and size, protein percentage and degree of resistance to the above-mentioned virus disease, the fungus Elsinoe batatas Jenkins and Viegas and the weevil *Cylas formicarius* F. The young seedlings resulting from controlled crossings were during the first critical weeks raised in pots and then transferred to the field, where by repeatedly pruning them the development of new shoots was stimulated. As soon as they had formed enough foliage 10 cuttings were taken from each seedling and planted in one row amidst two rows of the test clone. This planting constituted the first selection round. During the growth period and when harvesting some five months after planting, the performance of the new clones was compared to that of the adjacent test clone rows, whereby particular attention was paid to the characteristics mentioned before (except the protein percentage, because the equipment needed for simple and rapid protein determinations was not yet available). The worst 75% of the new clones were then discarded and the tubers of the best 25% were planted to provide cuttings for the second selection planting. The procedure during the second round was similar to that in the first, the only difference being that the

Table XIII. Relative proportional chemical composition of tubers and leaves

Contents as percentage of dry matter	A	B	1st C	D	2nd B	A
tubers - starch	61.9	59.5	61.[illegible]	61.3	62.4	63.4
sugar	15.6	11.4	12.6	10.8	13.5	11.1
crude protein	[illegible]	7.5	7.0	7.5	6.7	7.4
true protein	4.8	6.2	5.6	5.8	5.0	5.9
ash - total	3.3	3.5	3.3	3.3	4.0	4.6
K	1.24	[illegible].24	1.16	1.33	1.40	1.34
P	0.22	[illegible].24	0.21	0.20	0.21	0.16
Mg	0.15	0.12	0.10	0.10	0.09	0.[illegible]
Ca	0.16	0.23	0.16	0.25	0.22	0.29
Na	0.110	0.135	0.119	0.105	0.085	0.063
leaves - starch	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	6.2
sugar	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.6
crude protein	31.7	32.9	32.[illegible]	35.0	31.[illegible]	32.6
true protein	27.4	26.9	23.8	27.2	25.9	27.4
ash - total	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
K	1.14	1.26	1.44	2.66	2.06	2.17
P	0.53	0.48	0.37	0.46	0.46	0.15
Mg	0.39	0.43	0.45	0.45	0.45	0.47
Ca	0.74	[illegible]	0.17	0.15	0.85	0.54
Na	0.018	0.019	0.014	0.015	0.017	0.006
True/crude protein						
tubers	0.73	0.82	0.82	0.82	0.80	0.80
leaves	0.87	0.83	0.74	0.83	0.83	0.84
Dry matter as a percentage of fresh weight						
tubers	31.4	32.6	29.9	29.[illegible]	31.7	28.0
leaves	14.3	16.5	17.4	15.0	19.4	15.[illegible]

[illegible]

Plantings and treatments

			3rd				4th	
	B	A	B	C	D	E	A	B
	63.4	64.0	55.2	65.1	64.7	64.1	64.8	63.5
	11.8	15.9	13.1	11.2	11.7	13.6	9.6	11.6
	5.9	5.7	5.6	5.5	6.2	5.4	5.9	5.5
	4.7	4.1	3.7	4.7	4.7	4.0	3.4	3.7
	4.0	4.3	4.[illegible]	4.2	4.1	3.9	5.1	5.4
	[illegible].20	1.14	1.04	1.16	1.19	1.05	0.80	0.91
	0.18	0.15	0.14	0.17	0.09	0.14	0.14	0.18
	0.19	0.14	0.14	0.13	0.14	0.11	0.39	0.41
	0.41	0.39	0.28	0.26	0.19	0.24	0.11	0.13
	0.010	0.048	0.045	0.030	0.04[illegible]	0.05[illegible]	0.035	0.049
	[illegible]	6.9	6.5	5.0	7.7	4.2	[illegible].0	6.[illegible]
	[illegible]	[illegible]	1.2	[illegible]	[illegible]	[illegible]	3.3	1.3
	12.5	[illegible]	11.4	21.6	45.0	25.5	26.8	25.8
	27.5	23.[illegible]	27.1	16.0	24.6	24.6	23.9	21.2
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible].09	[illegible].49	[illegible].37	[illegible].26	1.15	1.14	3.68	4.23
	0.58	[illegible].34	0.42	0.46	[illegible].38	0.39	0.50	0.34
	0.42	0.40	0.40	0.42	0.26	0.40	0.27	0.23
	[illegible].96	0.78	0.54	[illegible]	[illegible]	0.80	[illegible].16	1.06
	[illegible]	0.009	0.004	0.003	0.004	0.004	0.016	[illegible]
	0.78	0.82	0.74	0.73	0.78	0.74	0.71	0.67
	0.40	[illegible].84	0.6[illegible]	0.51	0.82	0.83	0.85	0.84
	26.2	30.5	30.2	29.9	[illegible]	[illegible]	[illegible]	[illegible]
	14.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	14.4	14.9

rows were much longer. Again 75% of the clones were discarded. The remaining 25% were transferred to the third selection planting, where each new clone occupied a square plot the size of 20 m^2 and was surrounded by identical plots planted with the test clone. Again the same selection procedure was pursued. It was intended to discard once more 75% of the clones and to test the remaining 25% (that is 1½% of the initial number of seedlings) in full variety trials. However, on termination of the work this stage had not yet been reached. Of course it was too early to draw conclusions. Nevertheless, it should be remarked here that in the generative progenies thus tested several prospectively good clones occurred and that with respect to yields and properties of the tubers (size, shape, colour of the flesh and colour of the skin) there was evidence of an appreciable resemblance between each offspring in its entirety and the parents. At the highland station, established in 1962, a similar selection programme was started, using seed received from the U.S.A. and Japan. Unfortunately, this had to be broken off already a few months after its beginning.

MORE ABOUT THE EFFECTS OF ECOLOGICAL FACTORS

Earlier in this paper attention was drawn to the observation that the chemical composition of the tubers of four highland clones when grown in the lowland was different from that of the tubers of the same clones when in their original environment.

The farmers cannot alter climate and weather. Within certain limits, however, he is capable of changing the chemical and physical properties of his soil. It is important to know whether such changes influence yield and nutritional qualities of the sweet potato crop grown in this soil. For that reason in 1960, a rotation trial of many years' duration was initiated at the Manokwari station (lowland). The experiment was laid out as a latin square with five treatments being:—

A — continuously sweet potatoes, without fertilizer application;

B — continuously sweet potatoes, with fertilizer application as needed;

C — sweet potatoes alternating with weed fallow;

D — sweet potatoes alternating with *Crotolaria usaramoensis* Bak.;

E — sweet potatoes alternating with groundnuts.

The soil used for the trial was a sandy loam, rich in calcium, magnesium potassium and sodium, and poor in phosphorus and organic matter. It was therefore decided to apply to treatment 'B' from the second planting onwards 60 kg P_2O_5 per ha per planting and not to remove vegetable material (except the tubers and groundnuts) from any of the treatments throughout the duration of the experiment. When harvesting, samples consisting of tubers and 30 cm long top shoots were taken in each treatment and immediately sent by air to The Netherlands for analysis. The clone used was Genjem 2. The outcome of four plantings—after the fourth the trial had to be terminated—is presented in Tables VII and VIII. In amplification of the data it is mentioned that the rather long intervals between any two consecutive plantings were due to the weather in those periods; lack of rain prevented the planting of sweet potato cuttings. The exceptionally low tuber yields of the third planting were the results of an explosive fungus infestation (presumably a *Sclerotium* sp.) that in all plots killed the greater part of the foliage during the third and fourth month after planting.

Noticeable differences in yield and chemical composition of leaves and tubers due to treatment differences did not yet crop up in these four planting. It is not unlikely, however, that continuation of the experiment would eventually have shown quite a different picture.

SUMMARY

In the highland valleys of West New Guinea (West Irian) where an estimated three or four hundred thousand people live under very primitive conditions, the sweet potato is by far the most important crop. It accounts for almost one hundred percent of the human food intake in the area. As a result of this unbalanced diet various deficiencies occur, a general prevalence of protein malnutrition being the most serious of these. Introduction of sweet potato clones with a higher protein content than the traditional types seemed to be the best possible method to counterbalance the protein deficiency. In 1959, the Agricultural Research Station, Manokwari, in co-operation with several institutes in The Netherlands, started a research programme aimed at this goal. The work was still in its introductory phase when it abruptly came to an end in the first months of 1963. In the present paper a description is given of the investigation methods applied and the results obtained during these four years.

To begin with data about the chemical composition of the tubers of a number of popular lowland and highland clones are presented. The figures show that on the whole the former were richer in protein than the latter. In another experiment tubers of highland clones grown in their natural environment appeared to contain twice as much protein as tubers of the same clones when grown in the lowland. This may indicate that in the highland conditions for protein formation are better than in the lowland. Furthermore, in combination with the data obtained from the first experiment, it supports the assumption that it is possible to provide the highland communities with new clones which produce considerably more protein than the traditional types.

Storage of the tubers and the age on which they were harvested had, within certain limits, apparently no or only a minor effect on the composition of their dry matter. It was further confirmed that the carotene percentage of tubers of different clones varied widely and that it tended to be higher as the colour of the flesh was darker.

Analysis of young leaves and tubers of the same plants revealed that the dry matter of the former contained five to six times as much protein as that of the latter, thus proving that these young leaves, which the highland people use as a vegetable, constitute a very nutritious food.

As part of a comprehensive breeding programme methods to stimulate the flowering of various clones and to improve the germination of sweet potato seed were studied. Also a beginning as made with selection work in new clones developed from seed.

Finally the preliminary and still inconclusive results of a rotation trial, that was planned to extend over many years, are presented.

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DISCUSSIONS

Professor Harland :

In Dr. Ruinard's extremely interesting paper, he has mentioned in one part, the practice of utilizing leaves by roasting. I would like to know what he actually means by 'roasting'. I do not think that he has got the right word.

Dr. Ruinard :

It is not the word that I mentioned, but may be it is in the paper. Actually the leaves are roasted. The highland people do not have any cooking utensils so they put the unpeeled tubers into leaves, roast the whole thing and eat it.

Professor Harland :

What do the leaves look like when they are processed in this way?

Dr. Ruinard :

There is not much left.

Professor Harland :

Have you eaten these yourself?

Dr. Ruinard :

No sir.

Professor Harland :

I think that this is a lesson to us all. We go around telling the native farmers what to do, and I find that very few people have eaten these things that they talk about. Now this scheme for increasing the nutritional quality of the sweet potato is extremely important, but I notice that he began with high yielding clones. Now I think that it is rather unlikely that the high protein content would be found if the yield of carbohydrate is also high because, in general, there is a negative correlation between protein content and the yield. For example, if you select wheat for high protein content you have a concomitant reduction in yield. This also applies to sugar cane. Sugar cane with a high nitrogen content is lower in yield than the others. This is a point to bear in mind, that you must preserve a balance between carbohydrate and protein.

Dr. Ruinard :

I would like to comment on what you said about the relation between carbohydrate and protein. It is not what we have found in our analyses, but I should say that we have worked on this for only 3 or 4 years. We have only made a beginning and we should have gone farther in the direction which you mentioned, if we had had the time.

Professor Harland :

With regard to this remark of mine, I know that your work came to an abrupt and untimely end, but it is for the guidance of those working in other parts of the world. As far as my bibliographical researches have gone, they are not complete, but I understand that the Russians have got as high as 5 percent in protein as a result of their selection work.

Now it is worthwhile pointing out, that if you conduct analyses of a large random sample of available plants, the protein content will fall on a normal frequency distribution and from this normal frequency distribution calculating the standard deviation, the theoretical limit of selection would be about 3 times the standard deviation and that is the figure I think should be aimed at in selection. You have a ceiling towards which you can usefully work. Now, I understand that this civilization that you were talking about was a milkless civilization. Did they have any source of milk?

Dr. Ruinard :

No, I don't think so.

Professor Harland :

There are a series of general problems — world wide problems. The problem of the milkless civilizations and how they have resolved their problems is a part of a general phenomenon. The Chinese solved it by the domestication of the soya bean; and the Andean people resolved it by the domestication of the guinea pig, which is the protein unit of the Andean people. I just wanted to point out the general phenomenon that we have to consider milkless civilizations in general.

Dr. Ruinard :

I would like to comment on Professor Harland's remarks, for which I am very thankful. When he said about the Russians having found 5 percent protein in sweet potato — was it fresh weight or dry weight?

Professor Harland :

I do not know because I have not had access to the report.

Dr. Ruinard :

Just to prevent misunderstanding. I was speaking of the highest protein content of 1.7 in fresh material. Fresh material contains 20 to 25 percent under those conditions of dry material, which means that it was real protein — not crude protein — in those tubers was roughly 8 percent, which is really very good.

Dr. Yen :

With regard to Dr. Harland's question about what these things taste like, I have had to subsist on similar food and the sweet potato leaves are just like any other greens. They are very difficult to pick out because most of the highland peoples use at least six species when they cook and they are cooked together.

Now could I go on to something else? There is one warning about this course. A nutritionist working with a very isolated tribe, high up about 8000 feet I believe, and a very poor tribe indeed with very few resources, is supposed to subsist almost entirely on the leaves because they do not get many tubers. In this population there is a high incidence of goitre, and this is supposed to be directly correlated with the intake of leaves.

I do not know whether you can recommend high intakes of this material. Dr. Ruinard has a statement in his paper which he didn't make in his presentation which was the luxury of shifting cultivation. I will take issue at this as an observation after only one trip in Dutch New Guinea and some of the records from anthropologists who have been there since Dutch rule. I have never really seen a completely normal shifting cultivation in Dutch New Guinea myself. As for as the introduction of crops into native economies, I would agree entirely with Dr. Ruinard about the difficulty of doing such a thing. I would like to point out however, that since peasant vacation of these areas there have been various programmes to introduce plants as peanut, cabbage, bean, solanum, potato, tomato. All these plants were unsuccessfully introduced by missionaries and administrators especially on the Australian side, but the interesting thing is that when you revisit these areas the people adapt to the growing of these things or they are able to adopt them within the agricultural systems, they do use them now in the higher areas of New Guinea in some very peculiar ways. This can be compared with things like pyrethrum and coffee which have also been introduced and these have not been adapted into native sytems, they have to be worked on a plantation system. They are of no use in the society. The other one is viruses in the highlands. This is a very interesting comment of Dr. Ruinard. We collected many varieties from both sides of the New Guinea continent and we did not see any virus symptoms when we collected, but when we brought them into quarantine under very clean conditions but in a temperate zone, then they started to show in the most peculiar patterns, that we could not identify the viruses even with the help of plant pathologists.

Dr. Jones :

I too, would be stimulated to make a lot of comments on what Dr. Ruinard and Dr. Harland have said, but I would like to speak of one thing, and it relates to the current enthusiasm in some circles for trying to solve alleged protein deficiency in diets by increasing the protein content of the staple food stuffs. Dr. Ruinard does not give us his basis for concluding that there is a protein deficiency in these diets, and an imaginary reason for this is that probably there have not been any dietary or nutritional studies in this population of sufficient reliability to demonstrate whether there is a protein deficiency or not. But if there were, it would seem to be much more sense on economic ground to seek the solution not in the basic modification of the basic staple which as Dr. Harland pointed out, that if you start breeding for one trait you may loose the other, and you may be trying to sell by growing a crop that would yield less, just because you have a higher protein content. And this doesn't make much sense. A much more likely way of achieving what you may be after would be, I think, to look into the other foods that are eaten and see if it possible to introduce very high protein, supplementary foods. I would suspect that in highland New Guinea, the protein contribution which you would get from spinaches is quite high and quite significant. As you pointed out, although these diets are alleged to be bad, the population is there and has been for quite a long time, which suggests that they got protein somehow or other. I would also suggest that, as has been the case in many parts of Africa, if you had a true quantitative measure of the amount of pig meat consumed, you would find that this was not a trivial contribution.

Dr. Ruinard

I would like to answer Dr. Jones, about this remark. In the first place, you said something about the protein factor. The quality of the protein factor is probably what you meant. There was an investigation and it has been completed. A lot of tubers and leaves were sent out to the laboratories in the Netherlands, and they did some research there to find out the quality of these proteins. No conclusion has been arrived at, so we do not know how things are. It would have to take more time to complete this. This is for nutritionists and medical doctors to decide, and they decided this and became pretty alarmed about the situation, so they pushed us to do something about it, and in the second place there was no choice. It is very difficult in these primitive societies to change habits — to change feeding habits, habits of life and so forth — so what else can you do than to try to improve the food they have. They do not want to eat anything else.

SOME ASPECTS OF THE SWEET POTATO AND ITS AGRONOMY IN UGANDA

— *by* —

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Although the sweet potato is a crop of considerable importance in Uganda it has received only a little agronomic research attention. This paper presents a review of the existing knowledge pertaining to the growing of the crop in Uganda.

The importance of sweet potatoes in Uganda

Of the food crops grown in Uganda 75% of them, in terms of calories, are the perishable commodities, bananas, cassava and sweet potatoes. The position of sweet potatoes in relation to other food crops, both as acreages and total calorific values is shown in Table I. In 1959 the sweet potato-acreage grown was sufficient to provide 890 calories per person per day, assuming an average production of three tons per acre.

As a food-stuff the sweet potato is grown almost entirely for its tuber. Few references exist of the sweet potato leaves being used as a spinach; however the leaves are used as food for *Tilapia* in fish ponds, occasionally fed to cattle and sometimes given to housed pigs. In those areas with a good rainfall distribution, such as the fertile crescent around the North-Western parts of Lake Victoria, the sweet potato is normally harvested piece-meal and eaten within one to three days after harvesting, but in those areas with pronounced dry seasons and less reliable rainfall, part of the crop is sliced, dried and stored.

The distribution of the sweet potato crop in Uganda has been described in detail by McMaster (1962). The crop is to be found over a wide altitude range extending up to 7000 ft. Of note in Uganda is the large acreage of sweet potatoes in South Kigezi (in the south west of Uganda), an area equal to one forty-fifth of Uganda but which has about a sixth of the total sweet potato acreage. The largest sweet potato acreage may be associated with land pressure problems and the fact that Kigezi is a high altitude area where cassava does not thrive.

The relative importance of sweet potatoes from an acreage viewpoint, is indicated in Table I: for 1959 the 712 thousand acres grown were equivalent to 8.1% of the total acreage under cultivation in Uganda, and equalled .11 of an acre per head of population. The acreage per head of population for the period 1923-1963 for Buganda, Eastern Region and Uganda is shown in Table II.

It is of interest to observe in Buganda that as the acreage of Robusta coffee per head of population increased, so the acreage of the perishable food crops, bananas, cassava and sweet potatoes declined. This is shown in Figure I. It is possible to infer from this decline in acreage that there was a change in diet as more cash became available, but the more likely interpretation is that the increased cash earnings allowed the population in Buganda to be more independent of the vagaries of the weather (MacDonald 1963)

Table I. Food crop acreages (II) estimated yield per acre and total calorific values for Uganda in 1959

Crop	Acreage '000's	Yield/ acre**	Calories/lb F.A.O. values	Total calorific value (millions)
Beans	576.5	200 lbs	1565	180,444
Beans soya	5.0	200 "	1520	1,520
Cassava	676.1	5 tons	494	3,740,726
Grams	9.0	200 lbs	1565	2,817
Groundnuts (in shell)	426.8	800 "	1760	600,934
Maize	359.9	800 "	1615	464,991
Sorghum	705.2	600 "	1555	657,952
Finger millet	1270.5	600 "	1505	1,147,261
Bulrush	5.9	400 "	1580	3,729
Onions	2.0	2 tons	168	1,505
Pigeon peas	224.9	400 lbs	1565	153,307
Peas Field	31.4	200 "	1565	9,828
Plantains	1464.3	3 tons	320	3,148,830
Sweet potatoes	711.7	3 tons	440	2,104,354
Potatoes (Solanum)	9.6	3 "	317	20,450
Rice	7.4	600 lbs	1620	7,193
Sim-sim	235.0	200 "	2605	122,435
				12,368,276

* Census year
** Writer's estimate

Varieties

It is difficult to determine the exact number of varieties in use in Uganda, but it is likely that the number is well up in the hundreds. Nye (1938) recorded forty-seven varieties in one mutala in Buganda (the mutala was approximately one square mile in extent) and the writer has found twenty-seven varieties in the immediate vicinity of the University Farm at Kabanyolo.

Table II. Acreage per capita of selected crops for Uganda, Buganda and Eastern Region

Year	Uganda Pop in 000's	Uganda Total Acreage Per Head Of Pop.	Uganda Food Crop Acreage Per Head Of Pop.	Uganda Sweet Potato Acreage Per Head Of Pop.	Buganda Sweet Potato Acreage Per Head Of Pop.	Eastern Region Sweet Potato Acreage Per Head Of Pop.
1923	2975	.908	.763	.10	.29	.044
1924	3046	.993	.806	.15	.29	.048
1925	3107	.964	.765	.12	.20	.030
1926	3175	.978	.795	.13	.25	.047
1927	3245	.855	.668	.10	.17	.081
1928	3316	.958	.723	.11	.23	.104
1929	3389	1.121	.919	.13	.16	.104
1930	3464	1.115	.899	.11	.25	.074
1931	3536	1.224	.973	.16	.27	.136
1932	3605	1.127	1.022	.15	.21	.114
1933	3676	1.271	.966	.14	.21	.078
1934	3748	1.355	1.028	.13	.22	.071
1935	3821	1.249	.980	.12	.21	.079
1936	3896	1.354	.966	.12	.16	.060
1937	3972	1.408	.951	.11	.16	.075
1938	4050	1.389	1.002	.14	.15	.092
1939	4129	1.299	.976	.14	.09	.097
1940	4210	1.239	.914	.13	.08	.083
1941	4293	1.276	.957	.12	.09	.100
1942	4377	1.088	.848	.09	.05	.056
1943	4463	1.251	.954	[illegible]	.09	.103
1944	4550	1.120	1.065	.11	.08	.123
1945	4639	1.284	1.002	.10	.08	.131
1946	4730	1.220	1.016	.11	.09	.117
1947	4823	1.354	.969	.10	.09	.096
1948	4918	1.390	1.002	.10	.09	.109
1949	5041	1.339	1.003	.10	.09	.106
1950	5167	1.327	1.005	.10	.07	.110
1951	5296	1.327	1.002	.10	.07	.114
1952	5428	1.286	0.971	.10	.07	.120
1953	5563	1.488	1.151	.13	.11	.129
1954	5702	1.508	1.152	.10	.09	.119
1955	5844	1.409	1.052	.10	.07	.118
1956	5990	1.350	1.028	.10	.06	.110
1957	6139	1.299	.959	.09	.06	.090
1958	6292	1.301	.922	.09	.06	.111
1959	6450	1.365	1.042	.11	.07	.133
1960	6611	1.282	.971	.09	.08	.094
1961	6776	1.456	1.063	.10	.06	.131
1962	6445	1.361	1.013	.09	.05	.170
1963	7119	1.351	1.000	.08	.06	.080

The characteristics that make a sweet potato variety acceptable have not been fully determined. Certainly yield per acre is not a dominating character; in a trial of fifty-five sweet potato varieties carried out in 1948/49 at the Government Research Station, Kawanda, the lowest yielders gave 5 tons per acre, whilst the highest yielders exceeded 11 tons per acre. The fact that the poorer yielders persist may be accounted for by consumer preferences in terms of palatability and cooking characteristics, growth habit including length of growing period and disease and pest resistance features. Generally the consumer likes a red skinned variety, with a white flesh containing little fibre and, it is said by some consumers, a tuber which split exudes only a little latex. White skinned varieties are consumed, but are not so popular in the markets. The reason for this is said to be that some of the white skinned heavy yielding varieties are not so palatable, but they are indistinguishable from the palatable varieties. In general tuber shape is smooth or faintly ridged, although in Kigezi many of the varieties grown are deeply ridged and generally misshapen. Orange or yellow fleshed varieties are not so popular but do occur; Caroline Lea and Early Port are two such varieties although they are more virus susceptible than other varieties.

The peasant farmer rarely grows plots of sweet potatoes consisting of one variety and seems to prefer a mixture of several varieties; the reasons for this are variable.

Time of planting

In those parts of Buganda with a well distributed bimodal rainfall and reasonably fertile soils planting of sweet potatoes occurs in each month of the year:

No. of plots of sweet potatoes planted per month in Mukono Division (approx. 2,000 square miles in extend and situated in Buganda). Five year average (1952-1956).

Month	J	F	M	A	M	J
	1004	1287	1926	2174	1746	1513
	J	A	S	O	N	D
	1098	1183	1219	1065	1006	1787

In those areas with more marked dry seasons planting tends to be concentrated at the start of the rains, but there are also fairly extensive plantings around the swamps during the dry period both as a source of food and of planting material for the next season (Aldrich 1963).

Time of planting trials (unpublished report, Uganda Department of Agriculture) at Serere, a research station in the short grass area of Uganda, show that early planting gives the highest yields.

Place in the rotation

The sweet potato is a perishable crop and is often harvested piece-meal over a long period of time. This makes the sweet potato a difficult crop to include in arable rotation. Thus one finds the sweet potato being grown on small plots close to the dwelling place, outside the conventional arable rotation land. Sometimes the sweet potato is used as a closing crop in the rotation, but examples can be found where it is used as an opening crop after the resting period. Although it is not normally an estate or large farm crop, the sweet posto is included in the rotation on the Makerere University College Farm at Kabanyolo.

	First Rains	Second Rains
1st year	Grass	Sweet potatoes
2nd "	Maize	Sorghum
3rd "	Groundnuts	Sorghum/or maize
4th "	Sweet potatoes	Grass
5th "	Grass	
6th "	Grass	
7th "	Grass	Sweet potatoes

Sweet potatoes were chosen as the opening crop in the rotation on the grounds of experimental evidence in Kenya (Boswinkle 1960) which showed that wheat yields were highest when the crop followed an opening root crop, in this case solanum potatoes, in the absence of evidence to the contrary it was assumed that the relation hip between sweet postoes and maize would be similar. It was also considered that opening with sweet potatoes would reduce the cultivation costs in breaking the grass ley, as a fine seed bed would not be necessary, and the sweet potato crop should give a better seed bed for the following maize crop. Sweet potatoes conclude the rotation, which has the advantages of (a) providing a good seed bed for the grass crop (b) allowing a longer harvesting period and (c) providing continuity of sweet potato tubers for sale and ensuring the provision of adequate planting material from season to season.

The rotation has now been followed for six years at Kabanyolo. Whilst the rotation has been generally successful, the inclusion of the sweet potato crop has created timing difficulties, particularly in harvesting and selling thirteen acre fields yielding 4-9 tons of saleable tubers per acre. However improved and quicker methods of breaking the grass leys have reduced the timing pressure.

Planting material

Usually wilted apical cuttings, 12"-8" in length are used, and for preference they are obtained from mature plants. Trials at Serere (unpublished report Uganda Department of Agriculture) showed that for five varieties, 750-1350 lbs of cuttings were needed to plant one acre; it was also observed that one acre of swamp edge sweet potatoes provided sufficient material to plant 10 acres.

Generally, care is taken to ensure that the planting material is virus free. However mistakes are made, particularly as plants with a primary attack do not necessarily show pronounced symptoms.

Method of planting and spacing

In Uganda sweet potatoes are grown on hills, mounds and ridges, but rarely on the flat. The Department of Agriculture recommends the use of ridges, especially on sloping land; however in experiments no differences were determined between the yields of sweet potato tubers when planted on hills 2', 3' and 4' apart or on ridges 2', 4' and 3' apart. In experiments at the Makerere University College Farm on ridges 4-5 feet apart with 2 rows of cuttings per ridge at spacings

24, 12, 8, 6, and 4.8 inches apart, i.e. with populations ranging from 48,400 to 9,680 plants per acre, it was found by Aldrich (1961) that the spacing had relatively small effect on the total yields per acre, except at the lowest populations. However, there were considerable changes in the components of yield. Due to this ability to compensate there was relatively little change in the total yield per acre over a plant population range of 10,000-50,000 plants per acre, although when the population dropped to 5,000 plants per acre a significant reduction in yield occurred. Aldrich defined tubers as those with a diameter greater than 1 inch and his yields were of the order of 5 tons per acre.

In general the peasant cultivator in Uganda plants his cuttings by pushing them at an angle into the mound or ridge until more than 50% of the cutting is coverer; the drier the area the greater the percentage of the cutting that is covered by soil.

In 1963 a randomised block experiment was laid down by the writer, with the object of testing the adequacy of the planting methods used for sweet potatoes on the Makerere University College Farm. The experiment was designed to compare (a) planting on top of the ridge versus planting on the side of the ridge. (b) planting at 19,360 and 9,680 plants per acre and (c) comparing the conventional method of planting the vine cutting, i.e. pushing or drawing it into the ridge, versus having both ends of the vine cutting exposed.

The experiment consisted of five treatments:—

A. The normal planting method used on the Kabanyolo Farm, i.e. 4' 6" between ridge centres, with two rows of plants per ridge one row on each side of the ridge (about a third of the way down the ridge slope) and with one foot between plants in the row, giving a plant population of 19,360 plants per acre.

B. Planting on top of the ridge (4' 6" between centres) in one row with the individual plants being one foot apart i.e. a plant population of 9,680 per acre.

C. Planting on top of the ridge in one row, each plant being 6" apart i.e., 19,360 plants per acre.

D. The same treatment as B, but in this case the cuttings were drawn through the soil so that both ends were protruding.

E. The same treatment as C, but with both ends of the cutting protruding.

The variety planted was Bitambi, a popular local type. The tubers recorded were assessed by eye as being saleable, but were not less than ounces in weight. The harvested plots were 3 x 6 yards in size.

The results (Table III) of this experiment showed that there were no significant differences between the treatments in terms of yields of tubers, although there is a strong indication, nearly approaching significance, that the 9,680 plants per acre population is too low and causing a depression in the yield. There are however, highly significant differences in the number of tubers produced per treatment. These findings confirm Aldrich's findings that the sweet potato has "a considerable capacity for compensating for low plant populations by higher yields per plant" (Aldrich 1963). Such findings may be of importance to a farmer who plants large acreages of sweet potatoes all at the same time, but who wishes to stagger the harvesting i.e. he could use wider spacings for that part of the field to be harvested first.

Table III. Analysis of Yields obtained from a planting method trial, Kabanyolo 1963.

Treatment	Average yield per plot of tubers in lbs	Average yield in tons/acre of tubers	Tubers/plot	Average tuber wt. in lbs	Average wt. of tubers per plant
A. Normal planting	106	12.7	137**	.77	2.94
B. Planting on top of the ridge 1' apart	91	10.9	87	1.05	5.06
C. Planting on top of the ridge 6" apart	109	13.1	138**	.79	3.03
D. Planting on top of the ridge 1' apart with both ends protruding	91	10.9	97	.94	5.06
E. Planting on top of the ridge 6" apart with both ends protruding	100	12.0	137**	.73	2.78
S.E.	6.8 lbs		4.9		

It was thought that if the planting material was drawn across the ridge with both ends protruding i.e. more or less horizontal, rather than the normal vertical or sloped planting angle, then a greater number of tubers might be initiated on a larger number of nodes. The results show that there is neither advantage or disadvantage in drawing the planting material through the soil and leaving both ends protruding when using the variety Bitambi.

The other observation on this trial was that the farm labourers, who assisted in the harvesting of the plots, found it easier to harvest tubers from the plants that had been planted on the top of the ridge compared to those planted on the side of the ridge. As there is no significant difference in yield, whether the vines are planted on the top or the side of the ridge, then it would seem that planting on top of the ridge has the advantage, in view of the reduced harvesting effort.

Cultural operations during the growing period

The normal practice is to give the crop two or three weedings during the growing period, at which time the ridges, mounds or hills may be reshaped. As the sweet potato plots are normally situated near the dwelling places and in the care of the women folk the standards of weeding are in general good.

Oelse (1931) suggested that, in Malaya, sweet potatoes, which were prevented from rooting at the nodes of the creeping vines, increased their yields. An experiment conducted by the writer at Kabanyolo in 1964 to test this suggestion gave significant negative results when using the sweet potato variety Bitambi (Table IV).

Under the Kabanyolo conditions and using the variety Bitambi there was a highly significant decrease in yield when the plants were not allowed to root freely at the nodes. Whether this result is applicable to all sweet potato varieties is not known. Presumably there might be a difference between those varieties that produce tubers only from the nodes of the original planting material, and those that produce tubers at the nodes of the new vine growth.

Table IV. Yields obtained from a rooting at the nodes trial Kabanyolo 1964

Treatment	Yields per plot in lbs of saleable tubers	Yields per acre in tons of saleable tubers
A. Creeping vines disturbed weekly	15	2 9
B. Creeping vines disturbed bi-weekly	18	3.5
C. Creeping vines disturbed monthly	19	3 7
D. Undisturbed	27**	5 3**

S.E. 1 44

Manures and fertilizers

Little work has been done on the manuring aspects of sweet potatoes. As the crop is normally grown nearby the dwelling place and as this is the area in which most of the household waste is deposited then this may account for the reasonable yields often quoted for this crop in Uganda i.e. 5-7 tons of tubers per acre. Biggs (1940) states that, 'manuring with cattle manure has shown considerable increase of yield, and were this crop to be used in rotations it could with advantage be the crop to receive the manurial dressing.'

Working at Kabanyolo Aldrich (1968) found that applications of 450 lbs of sulphate of ammonia resulted in a highly significant reduction in yield and although smaller applications had less effect they also tended to give yield reductions. Aldrich also found that muriate of potash gave a significant decrease in the dry— matter content of the tuber.

In 1962 a trial was laid out by the writer at Kabanyolo to test the response of the sweet potato variety Bitambi to applications of compost, which contained farm yard manure. The applications were at 0, 2½, 5, 7½ and 10 tons per acre on a latin square lay out with each plot being 1/73 rd of an acre. The records taken were of the yield of tubers greater than 2 oz and the fresh vines. Although there were no significant differences (Table V), due to the variability within the experimental area and possibly because of the high yield level, there were indications that there were in fact responses to the application of F.Y.M./compost. The yield of fresh tops is recorded and could be of interest where live-stock is integrated with arable cropping.

Table V. Results of a F.Y.M./compost trial Kabanyolo 1962

Treatment	0	2½	5	7½	10	S.E.
Yield tons/ac/ tubers	12.86	13.43	13.79	14.65	13.50	.46
Yield fresh vines in tons/acre	8.79	8.22	8.79	9.71	10.52	.68
Yield vine dry matter in tons/acre	1.31	1.22	1.30	1.38	1.55	

Harvesting

Under peasant cultivation conditions the wife normally harvest the sweet potato tubers piece-meal; the mature tubers being removed individually and the plant being allowed to continue growing.

Where the sweet potato is incorporated into a rotation and grown on a large field scale, as on the Makerere College Farm, which grows twenty six acres of sweet potatoes per year, then harvesting problems can cause timing problems. The market is not over flexible and cannot absorb a sudden release of large quantities of tubers; in order to increase the harvesting period at Kabanyolo part of the crop is often harvested before it is fully mature.

Farm workers using spade hoes are expected at Kabanyolo to harvest between 400-800 lbs of tubers per task depending on the crop yield and soil conditions; about 1,200 lbs per task is considered the maximum.

Pest and diseases

The main pests and diseases are:—

1. Virus diseases
2. Spiny caterpillar (*Acraea acerata*).
3. Weevils (*Cylas* spp)

Little work has been done on control measures, with reliance being put on normal crop hygiene measures to control any outbreaks.

Farm Scale Costings

It is difficult if not impossible to determine costings for sweet potatoes grown on a peasant scale. The following data provides some of the costings which occurred in growing 9.5 acres of sweet potatoes at the Makerere University College Farm during the first rains of 1966.

	Total cost
Ploughing @ Shs 41.50 per hour	394.25
Discing @ shs 24.50 per acre	232.75
Ridging @ shs 30.00 per acre	285.00
Collecting vines – 37 mandays*	158.25
Carting vines	25.00
Planting vines – 44 mandays*	136.00
Gapping	60.00
Weeding – 67 mandays*	201.00
Weeding @ shs. 30.00 per acre	285.00
Harvesting – 106 mandays*	359.00
Carting	166.00
Total cost for 9.5 acres – Shs	2,302.50
Cost per acre – Shs	242.36

*Costs per man day vary depending on whether the labourers are permanent or casual.

Analysis of costings

Gross yield	– 119,168 lbs	– 12,544 lbs per acre
Gross revenue @	–	
6cts per lb	– Shs 7,150.00	– Shs 752.60 per acre
Gross cost	– Shs 2,302.50	– Shs 242.36 per acre
Profit	– 4,847.50	– Shs 510.26 per acre.

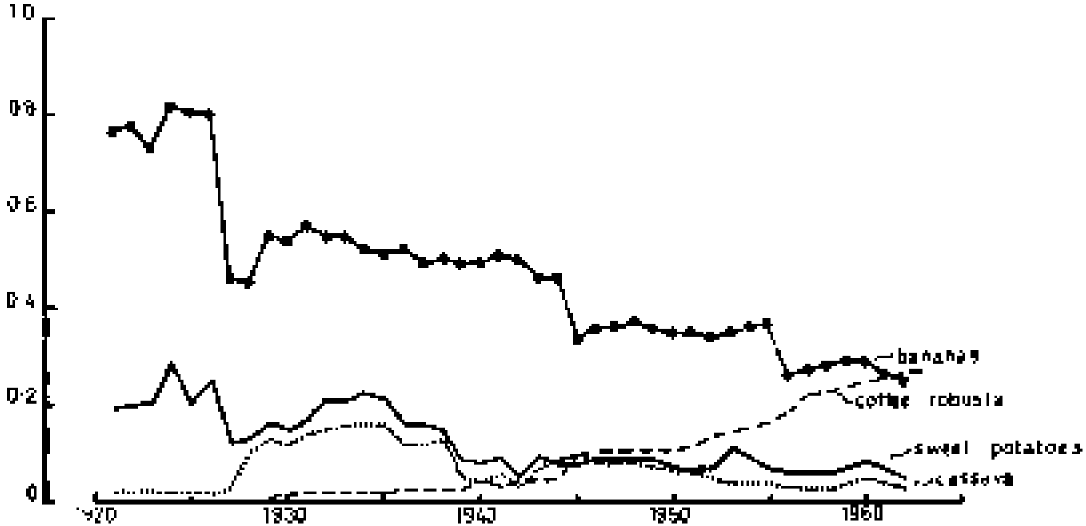
Summary

The paper presents a review of the existing knowledge pertaining to the growing of the sweet potato crop in Uganda. Figures, both total and per head, illustrating the importance of the crop, are given for the period 1923-1963 with an estimate of the calorific production. Reference is made to varieties, the consumer's preference and tuber shapes. Some details are given of time of planting and the place of the crop in rotations. The planting material used, methods of planting, spacing and post planting cultural operations are discussed and the results of trials at Kabanyolo Farm are given. Manures and fertilizers harvesting problems and pests and diseases are also mentioned. The paper concludes with some costings of growing the crop on a farm scale.

Acknowledgements

The author acknowledges the assistance of A. Foum and H.M.G. Henson who obtained and prepared the data included in the Tables and Figure 1.

FIGURE I



ACREAGE PER HEAD OF BANANAS, SWEET POTATOES, CASSAVA AND COFFEE ROBUSTA IN BUGANDA

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DISCUSSIONS

Mr. Williams :

What are the morphological characteristics of the sweet potato cultivar used in your experiments, on frequency of vine turning in relation to yield?

Mr. MacDonald :

In this trial we prevented rooting at the nodes. We did not actually turn them, we just lifted them from the ground.

Mr. Williams :

In this particular cultivar what is the vine tuber ratio?

Mr. MacDonald :

The vine tuber ratio of this one is about 1 to 1, 1.2 to 1. You would get about 2 lbs of tubers underneath the ground and about 2 to 3 lbs of vines above the ground. It creeps reasonably prolificly and you would find it growing to about 4 to 5 feet, and it roots reasonably freely at the nodes.

Mr. Williams :

Did you harvest at different periods of maturity? If so, what harvest dates did you use?

Mr. MacDonald :

They were all harvested at the same period, which was in this case, 5½ to 6 months.

Mr. Williams :

Did you grade your final yield? If so, what was the relationship of grade to time of maturity?

Mr. MacDonald :

These were all graded on saleable tubers, not less than 6 ozs. in weight each. Anything that was not saleable was discarded, and the difference in yield between the control and the one that was disturbed weekly, was of the order of a depression of 50 percent in yield of saleable tubers.

Mr. Williams :

On what soil type or types did you carry out your experiments?

Mr. MacDonald :

It was a clay loam.

Mr. Williams :

How would you characterise the growing season in your experiment in relation to rainfall, and other climatic conditions, and with season?

Mr. MacDonald :

In general, we are very fortunate with rainfall in Uganda. We have a bimodal rainfall which is split up into 2 seasons about 25 inches in each season, and distribution in general is good. This experiment was conducted in a field of 13 acres, of which I took over part. It had been planted early and I harvested mine at the same time as the farm.

Mr. Williams :

On how many trials did you base your conclusions?

Mr. MacDonald :

One

Mr. Williams .

I would like to make a comment. Mr. Haynes and I are investigating just this thing here at St. Augustine and in the Islands, but because of indications from the work of Haynes, Walter and Spence, that at least a three way interaction between type of cultivar, time to harvest and grade of tuber at harvest may exist, we found it necessary to look into the problem of the effect of nodal rooting on tuber yield against a broader agronomic background. We recommended that this sort of approach should be followed in such investigations.

Dr. Bolhuis .

To my astonishment I heard Dr. MacDonald say that in Uganda sometimes even if cassava wouldn't grow they still grow sweet potatoes. In our experience we find the reverse, that where sweet potatoes wouldn't grow any more you can get relative yield of cassava. What does he think about this?

Mr. MacDonald :

This is defined in terms of altitude. If you are thinking in terms of rainfall, as you go further north into the drier areas then you find cassava coming in and sweet potato going out, but if you go up in terms of altitude, then it's the sweet potato that would go to the higher altitude than the cassava. Possibly 1000 to 1500 feet high up.

Dr. Jones

I want to be honest about this. It is always possible to frame a comment like a question. It is a comment on this apparent constant composition of cropping in Uganda. I do not really share your confidence in the statistics of area planted, tabled food crops in Uganda, and I suggest that what you got is a statistical artifact in this thing that you presented at 83 percent constantly which arises from the way in which the statistics are sampled. That is, the statistics are essentially put together, on the basis of estimates of informed persons of what the area is in the district rather than on the basis of sample surveys. It is quite remarkable, and in looking at what you had on the board you would see that sometimes in the late forties, it shifted up to a new level and stayed there, which suggested an improvement in statistical procedures at that point. Now the question is, is it so?

Mr. MacDonald

In some respects you might be right, in that there are inspired 'guestimates', but the figures that I have worked on are in actual fact, honest attempts at sampling the acreage within Uganda. They were done on selected mitala of which a square mile was taken. One, Gombolola which is a small county, the actual physical acreage within each of the selected mitalas measured and then an acreage per taxpayer obtained which was then multiplied up by the number of taxpayers within Gombolola. I agree that there are errors in this and there are some problems with regard to the standard of measurement, but it was in actual fact, a statistical and accepted way of assessing the acreage. It was not an estimate by the Agricultural Officer after a trip round district in his car.

Dr. Edwards :

I thought I understood Mr. Macdonald as saying that in Uganda, in a recent year, the surplus of calorie supplies over needs, was about 100 per cent and the other trends he suggested would seem to suggest that this kind of excess was fairly normal. Is there any explanation of this? There seems to be a tremendous reserve to carry. Are there very substantial exports from the country? It is really very puzzling, and would seem to cast doubts on the absolute reliability of the figures.

Mr. MacDonald

There are several explanations for this. The first one is, of course, that the tremendous amount of food grown, about 75 percent, is in fact a perishable commodity, which cannot be easily stored. Less than 25 percent of the food which is grown is a cereal, or in a form which can be stored, and if you are growing a perishable commodity, then you are at the mercy of the weather, and this means that you cannot take an average season and grow sufficient acreage which would provide you with sufficient food in the average year, because this would mean 50 percent of the year in any ten-year period, you would be short of food and then 50 percent of the time you would have too much.

The other thing is that you are in a subsistence economy area where the family has to be independent for its own food supplies, and this of necessity encourages over production. This stuff, in actual fact, is not wasted. In many cases it is converted into beer, and the consumption of beer in Uganda is quite fantastic, particularly in places like Teso where they have a storable gain. You will therefore find it reasonable to accept the fact that the homicide rate of Uganda, which is the highest in the world is associated with the consumption of beer.

SWEET POTATO RESEARCH IN PUERTO RICO

— *by* —

Carlos G. Moscoso

The sweet potato (*Ipomoea batatas*), has always been a secondary crop in Puerto Rico, overshadowed by the leading cash crops such as sugar-cane, coffee and tobacco. However, at present the role of these crops is declining. This is due, among other factors, to the very low wages paid to farm labourers in Puerto Rico as compared with relatively high factory wages; the exodus of Puerto Rican farm hands from the Island to the mainland during the harvest season, and the resultant scarcity of farm labour; and competition with other sugar, coffee and tobacco producing countries. It has been often more economically feasible for us to import some commodities from other countries in which the cost of production is very low as compared to the high cost of cultivation in Puerto Rico.

On the other hand, while production of these other important cash crops in Puerto Rico has been declining during recent years, the production of root crops, especially the sweet potato, has remained rather stable. In some areas there has even been a noticeable increase in production. This is due to the fact that root crops have always been, and will in all probability continue to be, an important staple food in the daily diet of the Puerto Rican people.

When Columbus came to Puerto Rico in 1493, sweet potatoes were being cultivated by the Borinquen Indians as a supplement to their diet based mostly on fish and meat. The Indians cultivated five known varieties of sweet potatoes. The early Spanish settlers continued the cultivation of sweet potatoes as practised by the Indians; and through the succeeding centuries the number of edible varieties was gradually increased through selection. At the present time the Agricultural Experiment Station of the University of Puerto Rico is carrying out an active programme of sweet potato research and the scientific development of new and better varieties. There are written records of this project dating from the year 1929 to the present.

The growing of sweet potatoes at the Agricultural Experiment Station in Rio Piedras, Puerto Rico apparently began about 1923. During that year and the following year several varieties were tested for yield and quality. In 1925—26 there were 224 varieties grown and tested, and out of these varieties, 93 were selected for further experimentation.

From then up to the present time the Agricultural Experiment Station has continued introducing and testing new varieties for high yield. However, it was not until 1946 that real emphasis was given to our sweet potato research programme. At that time there was a possibility of establishing sweet potato canneries on the Island. By 1952 two canneries were processing sweet potatoes in Puerto Rico. During those years the author was in charge of the sweet potato research programme at the Experiment Station.

During this period the Station invited Dr. Julian C. Miller, a leading authority on breeding techniques of sweet potatoes from Louisiana State

University, to help us in setting up this new research programme at the Station. His advice and assistance were very valuable to us in improving our techniques and in getting the programme started.

One of the objects of this work was to develop high yielding yellow type sweet potatoes which would surpass the standard U.P.R. 3 variety and also be suitable for canning purposes. Tests made in our Food Technology Laboratory showed that a new variety selected from this programme and named "La Cobre" surpassed in quality all other varieties tested for canning purposes. From 1949 through 1955 the work was intensified and literally thousands of varieties of sweet potatoes were tested. The author introduced hundreds of varieties from Louisiana, Georgia, Florida and all the other sweet potato producing states of the Union. A survey of all the native varieties was made and a new programme with a larger collection initiated. Breeding plots were established in an effort to select better varieties for fresh market consumption and for industrial purposes. In addition about 5000 new seedlings were produced each year by breeding and from open-pollinated seed from selected plants.

In addition to the "La Cobre" variety which is outstanding as to yield, palatability and keeping qualities for canning purposes, two other outstanding yellow varieties were selected.

These are also high in carotene content, as is the "La Cobre;" and are highly resistant to drought and poor soil conditions. However, these two varieties, the "Canela" and the "Rico," do not peel quite as easily and consequently are not as suitable for canning purposes as the "La Cobre." Nevertheless, these two varieties were considered to be excellent for the fresh market.

While testing these yellow varieties a valuable mutation was found. While harvesting U.P.R. number 3 yellow type sweet potatoes, the author found four good size, well formed, *white* sweet potatoes on a string of yellow ones. These four white sweet potatoes were planted and on maturity, produced a high yield of the same white type. From this mutation was obtained the "Blanquita" variety which is excellent for the local fresh market. Actually, the native Puerto Ricans, particularly the rural people, prefer to eat the white type sweet potato rather than the more nutritious yellow type. This is of course, a matter of food habit.

Through a large number of regional tests conducted during 1949 to 1955 the best time of planting for sweet potatoes in Puerto Rico was established. In a series of tests, planting the sweet potatoes every month and subsequently harvesting every month, it was observed that the high yielding varieties produced a lower yield at certain times of the year. In addition it was observed that all the varieties followed the same pattern, producing proportionately more or less at certain times of the year. Continuing these monthly tests throughout the Island the author was able to establish that the best time of planting for sweet potatoes in Puerto Rico was from September to December.

In the past the farmers had always planted sweet potatoes after the sugar-cane harvest, which extends from January to June, and after the tobacco harvest in January. They thought that in this way they would be utilizing residual fertilizer from the tobacco fields. Also, late in the spring, i.e., toward the end of the sugar harvest, there was less work in the cane fields and consequently more labourers were available to plant sweet potatoes. You may be surprised to hear that this malpractice resulted in approximately a fifty per cent reduction in yield.

During the course of these experiments new planting techniques for sweet potatoes in the Tropics were developed. Contrary to the established practices, many of our farmers always planted sweet potatoes on flat land without digging trenches or making ridges. Others prepared trenches and ridges, but instead of planting the sweet potatoes on the ridges or hills, they always planted them down in the trenches. Naturally, with our heavy rains, the sweet potatoes often became water-soaked and many would rot. They were also difficult to harvest. The farmers were shown how to plant the sweet potatoes on the hills or ridges where they could develop well, without too much danger of moisture damage, and where they would also be easier to harvest. It was very difficult in some cases to convince these farmers to change their ways. In some communities I had to work through a well known and popular individual farmer. By setting up the experiment on the field of a leading farmer, and planting the sweet potatoes on the ridges, the benefits of this system were convincingly demonstrated at harvest time. In this way the adoption of ridge planting soon followed.

Along with these experiments, the Plant Pathology and Entomology Departments of the Station also did research on diseases and insect pests attacking sweet potatoes. They concentrated on the sweet potato weevil *(Cylas formicarius)*, which was causing great damage to our plantations. This was soon controlled after a series of tests with insecticides. At that time, Aldrin, which was then new on the market, was found to be very effective. Naturally, the Station has continued testing the newer insecticides as they have appeared on the market; but with the use of Aldrin alone the sweet potato weevil has practically disappeared from our sweet potato plantations in Puerto Rico.

In 1955 the author published a technical paper concerning all the experimental work which we had done with sweet potatoes up to that time, in order to aid our Island farmers. This was the first bulletin on sweet potato cultivation ever published by the Agricultural Experiment Station of the University of Puerto Rico.

Unfortunately, after developing all this research and new interest in the sweet potato as an industrial crop in Puerto Rico, the two canning plants which had been established failed, due to economic reasons. They could not compete with the mainland canneries; and also the native population was not accustomed to eating the canned product. Nevertheless, as stated before, since the sweet potato is a basic staple in the Puerto Rican diet, cultivation of the crop, particularly the white varieties, has continued at a stable rate and has even increased. From time to time the Island exports sweet potatoes to the continental United States; but on a limited basis. Our production is mainly to supply the local fresh market demands. Our Agricultural Extension Service has been attempting to educate the rural people as to the higher nutritive value of the yellow type sweet potatoes. Housewives in the larger towns and cities apparently are becoming more conscious of the vitamin content and nutritive values of foods and there is a greater demand for the yellow type sweet potatoes in the urban supermarkets. Gradually the consumption of the yellow type is increasing. In spite of this the white type is still preferred by the majority of the population.

The Agricultural Experiment Station of the University of Puerto Rico still maintains its programme of sweet potato research. In recent years there has been increased interest in, and greater demand for all root crops in Puerto Rico; sweet potatoes, yams, tanias, cassava, dasheen and others. More attention will be given to starchy crops research in the future.

Although there are no sweet potato canning factories operating in Puerto Rico at present, the future outlook seems to be quite favourable for the increase of sweet potato production on the Island. The export market for shipping Puerto Rican sweet potatoes to the United States can be developed if the desirable standards for an export crop can be maintained.

However, an overall educational and advisory programme must be carried out to aid the farmers who still cling to outdated agricultural practices. Continued co-operation among the various government agencies; the education of the farmer, and his acceptance of modern techniques of production and harvesting; the prospect of a continental United States market for the fresh product, the continued increase in demand for sweet potatoes for local consumption; and the development of a more efficient storage and marketing system are all important factors that can make the sweet potato a crop of importance in our economy.

The sweet potato will always be a dependable subsistence crop for the daily diet of our people. During critical times, such as hurricanes, shipping strikes, wars, and other crises, when foods imported from the continental United States could not be shipped regularly on time, the sweet potato, a native Puerto Rico food, has always been seen on the tables of rich and poor alike.

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PROPAGATION OF SWEET POTATO WITH DIFFERENT KINDS OF CUTTINGS

— *by* —

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Usually, vegetative multiplication of the sweet potato does not cause special problems. Under favourable conditions, however, or in cases where it is desirable to multiply varieties as quickly as possible, the question may arise whether it is necessary to use cuttings of 30-40 cm in length. In moderate and subtropical climates, sweet potato which is strictly speaking a tropical crop can only be grown in the summer season. In the winter season young shoots (draws) are torn from the sprouting tubers and from plants grown from such shoots cuttings are planted in the field. As these cuttings should have a length of 30-40 cm a large quantity of mother plants must be available. If the cuttings could be reduced in length the number of mother tubers could also be restricted.

Only a limited number of publications on this subject are existent. According to Strijdom and Hyman (1965) in S. Africa cuttings with a length of 30–40 cm are used. Boswell (1950) states that the best cuttings are those of about 20 cm of the top-ends of the vines, base cuttings should be 60-90 cm. In his compilation Mac Donald (1963) mentions that cuttings vary in length. In Trinidad cuttings are used from 20-30 cm. Van Rheenen (1960) prefers top cuttings, followed by middle cuttings and base-cuttings. According to him the best length is 20-30cm. The same opinion is forwarded by Galang (1932) Reijnvaan (1932), Wood (1937) and Fielden (1940), Johnson & Ware (1956) and McIntosh (1937).

In one article only by Anon. in Farming in South Africa (1946) the best length of cuttings is given as 20 cm. Nearly all the authors state that plots planted with top cuttings are yielding better than those planted with base-cuttings.

In our experiments we wanted to determine whether there was any difference in growth between top cuttings and base-cuttings and between cuttings of different lengths. Other questions concerned the possibility of growing plants from short-cuttings when quick multiplication is wanted.

Materials and experiments

Experiments were laid out in the hothouse and in the open with cuttings of two cultivars called A and B. Cultivar A is a quick grower with long internodes and small, heavily incised, leaves; cultivar B is a slower, sturdy growing one with short internodes and large entire leaves. During the course of the experiment the main stalk was measured at weekly intervals; at the end of the experiment the total length of the main stalk and branches was determined. Above ground parts were dried and weighed as dry matter. Per object 4 cuttings were used.

The first experiment was laid out in a hothouse with cuttings of the two mentioned cultivars. The results of measurements and weighing are compiled in Table 1.

Table I. Average lengths of main stalks of weekly intervals of top and base cuttings, total lengths of all shoots and dry weights.

Cultivar A.	Weeks							Av. total lengths of all vines	Av. dry weight of vines in grs
Top cuttings	1	2	3	4	5	6	7		
20 cm	3	14	64	130	188	249	284	931	30.0
30 cm	6	23	81	144	204	266	312	1027	35.0
Base cuttings									
20 cm	–	5	50	105	156	218	257	721	24.5
30 cm	1	10	65	115	174	241	295	1147	35.0
Cultivar B.									
Top cuttings									
20 cm	1	7	19	36	56	75	90	114	24.0
30 cm	3	11	27	48	69	87	105	184	32.0
Base cuttings									
20 cm	1	1	8	17	27	37	46	51	9.0
30 cm	–	5	21	41	55	71	90	187	25.0

The figures compiled in Table I show an enormous difference in growth in cuttings of the two cultivars. In cultivar A the difference in total length of the top cuttings does not deviate much from that of the base-cuttings, however, but there exists a distinctly minor growth in the shorter base-cuttings. Top cuttings of cultivar B of 30 cm show a much better growth than those of 20 cm; in the base-cuttings the difference is even more striking. The dry weight of the vines produced by the base-cuttings of 20 cm falls far behind that of all other cuttings.

In the second experiment we tried to find out whether cuttings of short lengths could be useful for propagation. The lay-out of the experiment was the same as the first one. Only top cuttings were used. As this experiment was started at the same time as the first one and under the same conditions, some figures from Table I were also used. The results are compiled in Table II.

Just as in Table I the results in Table II point to a considerable difference in growth capacity between the two cultivars. In both cultivars the longer cuttings initially had a large advantage over the shorter ones but in the run of the experiment the differences in growth tended to diminish. It is remarkable, however, that in both cultivars the 15 cm cuttings were the fastest growers. From these results it can be concluded that under favourable conditions even short top-cuttings can be used for propagation.

Table II. Average lengths of main stalks at weekly intervals of top cuttings of different lengths, total lengths of all shoots and dry weights.

Length of cuttings in cm.	Weeks 1	2	3	4	5	6	7	Av. total length of vines	Av. dryweight of vines in grs
Var. A									
5	–	3	20	62	100	150	207	633	18
10	–	4	28	74	113	167	233	608	17
15	1	9	47	105	161	222	288	1071	29
20	3	14	64	130	188	249	284	931	24
30	6	25	81	144	204	266	312	1027	35
Var. B									
5	–	2	3	12	22	43	68	81	20
10	–	4	13	30	52	79	101	130	29
15	–	5	17	38	59	82	110	281	42
20	1	7	19	36	56	75	90	114	24
30	3	11	27	48	69	87	105	185	32

A third experiment was laid out to determine whether besides the short top-cuttings also short base-cuttings could be used for multiplication. As it is known that multiplication of cocoa with single-leaved branch cuttings is quite feasible, the same was tried with sweet potato. The results of the weekly measurements, total length and dry weight of the vines are compiled in Table III.

Table III. Average length of main stalks, total length and dry weight of all vines of short base cuttings.

	Weeks 1	2	3	4	5	6	7	Av. total length of vines	Av. dry weight of vines
Cultivar A	–	1	6	27	52	95	143	274	8,7
Cultivar B	–	–	2	4	7	11	16	16	2,5

The figures in Table III show that if necessary even very short single-leaved base-cuttings may be used for multiplication. The results with cuttings of the quick growing cultivar A were, however, much better than with those of the slower growing cultivar B.

The experiments described above were simultaneously executed in the open, where the temperature was generally about 10°C lower than in the hothouse; therefore growth was much slower. Therefore these experiments were continued for 6 weeks longer than those in the hothouse. Weekly measurements of the vines were eliminated and data were only collected at harvest time. The results are compiled in Table IV.

Table IV. Average total length of vines and average dry weight in grams of cuttings grown in the open.

		Av. total length	Av. dry weight in grs
Cultivar A			
top cuttings	10 cm	724	52
	20 cm	922	67
	30 cm	1006	76
base cuttings	20 cm	908	56
	30 cm	1006	72
Cultivar B			
top cuttings	10 cm	90	18
	20 cm	186	40
	30 cm	167	39
base cuttings	20 cm	74	15
	30 cm	122	33

These data indicate that the difference in growth rate between the cultivars are the same as in the experiments in the hothouses. With cultivar A, however, the growth rate and the ultimate dry weights were much higher than with cultivar B. Only top-cuttings of 20 and 30 cm length came somewhat near to cultivar A as to dry weight.

Summarizing the results of all the experiments leads to the following conclusions:

1. With both cultivars the growth rate of the top and the base cuttings of 30 cm is better than of those of 20 cm.

2. Whenever quick multiplication is desired top cuttings shorter than 30 cm may be used, even top cuttings of 5 cm length show a fair growth.

3. In the above mentioned cases short base-cuttings of cultivar A, a quick growing cultivar, still can be used, with cuttings of a slow growing cultivar, however, the results were disappointing.

4. Experiments with cuttings of the same cultivars in the open did show that the results generally were in accordance with those laid out in the hothouse.

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DISCUSSIONS

Mr. MacDonald :

Could I ask Mr. Bolhuis, with regard to his cuttings—he tried cuttings of various lengths. Was any work done on the period of wilting? I have seen quite a bit in the literature stating that wilted sweet potato cuttings are much better than unwilted ones, but I have never come across an actual experiment that demonstrates this. Has any work been done by yourself ?

Mr. Bolhuis :

I agree with you. I have never come across anything like it, and we used non-wilted cuttings. Entirely fresh material. In Java, under native planters, it is a well known fact that from every three years you have to plant your sweet potatoes by means of tubers instead of cuttings, and we tried it out for 13 successive generations—one series of cuttings only, another series for three years by tubers, and one series is entirely by tubers. After 13 generation there was no difference.

Professor Milthorpe :

I wanted to raise the question of relation of time to tuberisation in relation to the source of cutting. If one takes cuttings from old plants or plants which are already forming tubers, do they initiate tubers more quickly than those from non-tuberising plants, or from cuttings which arise directly from the root tuber? Secondly, does the presence of part of the mother tuber have any effect on the time to initiation of the tubers ?

There is, I think, in the Irish potato, evidence of possible presence of some tuberising factor which is developed with age in the mother tuber.

Mr. Bolhuis :

I am sorry I cannot tell you very much about this, not because I am not familiar with sweet potato, but because my connection with sweet potatoes was quite incidental.

Mr. Degras :

This is about a question of Dr. Milthorpe. We are now beginning an experiment to decide whether there is or not, a part of determination of tuberisation in sweet potatoes, not only with the part of the plant which is taken from multiplication but also with the time of the year when we take the cuttings. We think that we could not have two different patterns coming in that process. First, difference of the part of the plant at the same time, and also different stages of the development of the plant all along the year, and we are now beginning, we started last month, to see what there is to this idea. It is a very interesting problem.

PROBLEMS OF YAM CULTIVATION IN BARBADOS

— by —
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The yam, *Dioscorea alata*, is the major staple foodstuff grown in Barbados: over 15,000 tons were harvested in 1965/66, valued at about 1.3 million dollars. Yields are, however, not very high, averaging only some 4-5 tons per acre. There are several distinct strains of *Dioscorea alata* in Barbados—clonal propagation is the rule—and of these the White Lisbon (locally called "Crop Libson") is the most extensively grown as it is regarded as having the best flavour and texture as well as being the highest yielder. It has, however a poor shape, the tubers being large and spatulate, with toe-like outgrowths, making them difficult to harvest and not very suitable for packing nor attractive for the growing export market.

Up to about two years ago yams in Barbados had received little systematic study. They are invariably grown on land which has been prepared and ploughed for sugar cane, not especially for yams—they are grown as a true catch crop in the interval between the harvesting of one crop of cane and the planting of the next. We did not know whether the spacing of 5ft. x 5ft. imposed on them by this system was suitable: we knew nothing of any interaction there might be between cultivars and spacing, indeed, we are not always quite certain just what cultivars we are actually dealing with. We did not know whether there was any difference in top or middle or bottom cuttings used for planting material, nor did we know anything about their fertiliser requirements, nor the interactions between rainfall, soil and yield. Further, there have been recent outbreaks of two diseases which have in places been serious — a leaf disease identified as Colletrotrichum and a tuber rotting during storage of the harvested material. Finally we were uncertain as to what causes the aerial parts to die off at about the time of maturity.

With the growing interest about crop diversification that is developing in Barbados and the greater awareness in recent years of the importance both social and economic, of locally grown foodcrops, it is not surprising that the lack of precise knowledge about so important a crop as yams became a matter for concern. Just two years ago, therefore, systematic experiments were started on this commodity, and in this report we shall try to summarise, very briefly, what has been attempted and what has been accomplished. You will appreciate that much more than two years' experimentation is required for many definite conclusions to be drawn, but even in this short time certain trends are so clear that there can be no doubt as to the ultimate answers. However, there are still very large gaps in our knowledge, and these will also be touched upon.

Barbados, in spite of its small size, has a wide range of soil types and well marked rainfall zones. In any programme of field experiments, therefore, it is necessary to lay down a number of experiments in different parts of the island, and this was done in both the 1965 and 1966 series.

(1) *How a yam grows*

As a basis for further understanding growth analysis observations were undertaken on yam plants a large number of measurements being carried out on white lisbon yams in an intermediate rainfall area. The observations included:—

Area of ground covered

Total length of all stems

Number of leaves

Total area of leaves

Leaf area index

Total fresh weight of shoot system

Dry weight of shoot system

*Fresh weight of root system (not including tubers)

*Dry weight of root system (not including tubers)

Fresh weight of tubers

Dry weight of tubers

The progress of growth is shown in Figure 1 and may be summarised in words as follows:—

(1) Both the shoot and the roots system developed very slowly for the first eight weeks but then grew with increasing rapidity to the 30th week after planting, subsequently dying back quite sharply. Secondly spires — i.e. new shoots emerging from below ground—appeared at 10-12 weeks, and this really marked the onset of development of the shoot system. It would seem that previously the plant had been living almost entirely off the old tuber, but the appearance of second spires was the start of an independent plant.

(2) Outgrowths of undifferentiated meristematic tissue appeared at about 10 weeks and from these grew the new shoots that formed the "second spires", and a vigorous root system.

(3) Bulking of the tubers started at about 22 weeks, and was extremely rapid after 26 weeks up to the 36th week, when the yams were harvested.

(4) The general dying back of the shoot system after 30 weeks already noted in (1), was associated with a cessation in growth of the stems and a reduction in the number of leaves. (It may be noted in passing that the aerial portions of a well grown yam plant are very substantial; at 30 weeks, the average total stem length (i.e.) stem and branches) was 220 feet and the number of leaves per plant was approximately 500. One plant was measured with total stem length 410 feet and another with 632 leaves).

(5) The leaf area index (i.e. the area of leaves divided by the area of ground covered) rose rapidly to a figure of 2.7 by the 16th week and then remained very steady until the 26th week, when it fell rapidly, owing to the loss of leaves from the plants. The literature suggests that leaf area indices above

*In practice the adequate removal of the root system was not achieved and these observations were abandoned.

3 may imply excessive mutual shading; there is thus no evidence from the current observations that the yam plant, spaced 5ft. x 5ft. trailing on the ground, is lacking on photosynthetic efficiency. On the other hand, shading may be causing leaf fall from the lower shoots, and it is quite possible that elevating the plant on stakes, as is done in several West Indian Islands (but not in Barbados), may allow the development of many more leaves on the shoot system.

(6) Rainfall throughout the growing period was fairly well distributed and no direct effect on the growth rate could be discerned.

So here we have a picture of the life cycle of the yam plant, albeit it is only for a single cultivar under one set of conditions. Even so, it has given those of us who worked on this crop an understanding that we did not possess before.

In 1966 observations were carried out on the rate of the development of tubers of four cultivars—White Lisbon, Coconut Lisbon, Oriental and Hunt. The growth curves are shown in Figure 2; distinct differences in rates of development are shown the more rapid bulking of Oriental and Coconut Lisbon being clear ; Oriental has long been established as an early variety for harvest in November/ December. There are now indications that Coconut Lisbon can be harvested around the same time. Hunt also seemed to mature fairly early (30-32 weeks from planting), but White Lisbon develops more slowly for a considerably longer period.

(2) *Spacing*

In the 1965 experiments, on five localities, randomized plot layouts were used, the plots being relatively small, 40 x 20 ft. (800 sq. ft.). The actual spacing treatments were as indicated in Table I; yields per acre for the five localities are also shown.

The considerable increase in yield with closer spacing is clear although there were anomalies, mainly due to death of plants and the rather small numbers involved. Closer spacing also led to a reduction in size of the tubers and a larger proportion of better shaped material.

There was no very close correlation between the total rainfall and the ultimate yield; further analysis of the rainfall figures, however, showed that the amount and pattern of rainfall in the first few weeks after planting was extremely important, affecting the establishment of the plants.

Table I. Yams 1965: Spacing Experiments (Cultivar White Lisbon)

Spacing (feet)	Plants per acre	Yield in lb. per acre plantations Nos. (1)					Average of 5 Plantations
		1	2	3	4	5	
2.5 x 2.0	8,700	34,500	24,500	22,600	18,900	16,500	23,580
5.0 x 2.0	4,350	28,500	20,000	15,500	16,300	9,900	17,960
5.0 x 3.0	2,900	19,800	16,600	11,700	13,800	10,800	14,540
5.0 x 4.0	2,200	18,800	16,800	12,800	13,400	11,600	14,680
5.0 x 5.0	1,750	22,300	12,200	7,500	12,900	5,400	12.060
5.0 x 6.0	1,450	16,200	12,800	9,800	11,600	8,500	11,780

Rainfall during the growing season was as follows:

Plantation 1 .... 50.56 inches   " 2............ 43.79 "
" 3 .... 36.38 "   " 4 .... 51.80 "
" 5 .... 36.22 "

Along with these small scale experiments a single large scale observation was made on one plantation where, in a 5 acre field otherwise planted at the conventional 5ft. x 5ft. an area of 1 acre was planted 5ft. x 2ft. 6 ins. The results were striking (Table II).

Table II

Planting distance	Yield per plant (lb)	Yield per acre (lb)	Value of crop per acre ($) *
5'0" x 5'0"	7.8	13,600	476.00
5'0" x 2'6"	6.9	24,000	720.00

* *Valued at 3.5 cents per lb. for 5'0" spacing and 3.0 cents per lb. for 5'0" x 2'6" spacing because of the higher proportion of small tubers in the latter case.*

In the 1966 experiments all plantings were made on ridges 5 feet apart (as this was the distance between ridges required for sugar cane cultivation), but spacing of 5'0" and 2'6" along the ridge were used. Two cultivars, White Lisbon and Coconut Lisbon, were used in these experiments. Results are summarised in Table III.

On the field scale, then, we have a consistent increase in yield with closer spacing, averaging 3,922 lbs per acre for White Lisbon and 4,238 lbs per acre for Coconut Lisbon. These increases are worth about $157 and $180 respectively at the current price of 4 cents per lb.

All the yields were relatively low; this is attributed to excessive rainfall and periodic waterlogging of the soil.

(3) *Planting Material*

It is customary in Barbados to use slices of tuber as planting material, each weight 4 to 6 ounces. A single tuber will provide 3 to 5 or 6 cuttings. Sometimes, however, small whole yams, also weighing 4 to 6 ounces, (which are virtually unsaleable) are planted. These are known as seed yams. It is frequently stated that the top cuttings grow more quickly and give higher yields than middle or bottom cuttings. Seed yams also are regarded highly by planters.

Table III. Yams 1966: spacing trials

Location	Planting distance	White Lisbon Yield per acre (lb)	Coconut Lisbon Yield per acre (lb)
1	5'0" x 5'0"	18,097	10,433
	5'0" x 2'6"	19,650	17,967
2	5'6" x 5'0"	9,713	9,090
	5'6" x 2'6"	12,583	13,623
3	5' x 5'0"	5,873	3,903
	5'0" x 2'6"	10,937	6,838
4	5'0" x 5'0"	7,340	6,483
	5'0" x 2'6"	10,893	9,660
5	5'0" x 5'0"	8,653	6,113
	5'0" x 2'6"	14,373	9,800
6	5'6" x 5'0"	8,920	7,250
	5'6" x 2'6"	12,387	10,690

Plantation 1 high rainfall area
" 2, 3,4 intermediate rainfall area
" 5, 6 low rainfall area

One experiment has now been done in which top, middle and bottom cuttings, and seed yams were compared. The first observations were on the percentages that sprouted within certain periods (Table IV).

Table IV. Yams 1966 Planting material: rate of development

Period after planting	Percentage sprouted Top Cuttings	Middle Cuttings	Bottom Cuttings	Seed yams
4 weeks	63	49	53	62
10 weeks	98	98	99	92

Thus it appeared that indeed top cuttings and seed yams sprouted rather more rapidly than middle and bottom cuttings, but the others caught up eventually. Final yields are shown in Table V.

Table V. Yams 1966 Planting material and yields

Yields in pounds per acre

Top Cuttings	Middle Cuttings	Bottom Cuttings	Seed yams
10,483	9,475	9,521	8,131

Although it appeared that the top cuttings did give a higher yield, this was not significantly different from the middle and bottom cuttings, the lower yield of the seed yams was clear: the difference was significant at the 20% level compared with that from cut pieces.

(4) *Fertilising*

There have been no systematic experiments in Barbados to ascertain when fertiliser should be applied to yams, though from the growth analysis described above it seemed logical to apply it at "second spires", the time when the main root and shoot system were starting their independent life, and this was done in the experiments of 1965 and 1966.

Experiments on small plots in 1965 showed no discernible responses to fertilizers, but the experimental error with these plots was so great that only very major treament differences could have been detected. In 1966 the experiments were conducted on the field scale, with strips of treated and untreated material alternating, the area of each strip being approximately 1/6 acre; the total area of each experiment containing three replications of the fertiliser treatments was thus 2 acres. This layout not only had the advantage of size and of being directly translatable to commercial conditions, but the alternating strips of control plots showed fertility trends across the fields, which in some cases changed by as much as 100% over a distance of only 25 feet. Further, this layout was easily operated with plantation labour. (The same type of layout was used in the spacing experiments already described). Experiments of this kind were put down on eight widely differing localities. In six out of the eight localities increases in yield followed the application of 2 cwt. of a fertiliser of formulation 8:12:25; in the other two instances there were decreases in yield. However, the increases were in some cases substantial, though not statistically significant, amounting to an average of 1,200 lbs. per acre (10%) for all eight localities (Table VI). When the fertiliser was increased to 4 cwt. per acre further increases were shown in only four instances, and there were decreases in four, though the average difference from the unfertilised control was an increase in yield of 900 lbs. per acre (9%).

Previous experiments on fertilising yams in Barbados have also failed to show significant responses, but in view of the current results it would be difficult to say that there was truly no response. With changes of up to 100% in control plots only 25 feet from each other it would require a large response indeed to be statistically significant.

The poor response to 4 cwt per acre of 8:12:25 is peculiar: this is still a relatively low level of fertilisation. The results may perhaps be associated with the exceptionally wet growing season of 1966, yields were lower than in the dry year of 1965 and may have been limited by periodic waterlogging of the soil, and this also may have affected the response of the plants to fertilisers. Much more research is necessary.

Table VI. Yams 1966—Effect of fertilising.

Location	Treatment	Yield per acre	Increase (lb)	% Increase
1	I	17,980		
	II	22,360	4,380	24
	III	21,933	3,953	22
2	I	10,807		
	II	12,497	1,690	16
	III	13,760	2,953	27
3	I	12,892		
	II	11,827	– 965	–7
	III	13,783	981	8
4	I	12,260		
	II	11,260	–1,000	–8
	III	11,780	– 480	–4
5	I	16,537		
	II	17,633	1,096	7
	III	15,377	–1,160	–7
6	I	11,253		
	II	11,325	72	0.6
	III	12,410	1,159	10
7	I	7,722		
	II	10,207	2,485	32
	III	6,953	– 769	–1
8	I	11,100		
	II	12,967	1,867	17
	III	11,837	737	7

Plantations 1, 5, 6—High rainfall area
2, 3, 7—Intermediate rainfall area
4, 8—Low rainfall area

Treatments: I—No fertilizer
II—2 cwt. per acre 8:12:25
III—4 cwt. per acre 8:12:25

(5) *Rainfall and Soil*

No systematic study has yet been made of the effect of rainfall and yield. It is a matter of common observation that in certain years with very low rainfall the yield of yams has been low, and it may be possible to find statistics which can be analysed. We have no idea at all whether rainfall in the early part of the growing season is more important than in the late, or viceversa, except that, in the 1965-66 experiments, the effect of early rainfall on the establishment of the crop,— both in respect of the number of plants surviving, and of their subsequent development, appeared to be important. We hope that in the course of the next few years information of this kind will be developed.

There is equally little knowledge about the effect of soil type and conditions on the growth of yams. There seems to be no area in the island, where, if rainfall is adequate, yams will not do well; on the otherhand, for no reason so far ascertained, a crop may be poor under conditions which were expected to give a good yield. Further, every plantation manager can point out fields in which he will say that yams never thrive, though there is no clear reason why this should be so.

One observation of interest in this year's experiments, however, is that even with the very high rainfall in all parts of the island, the plantations in the higher rainfall areas gave higher yields than those in the lower rainfall regions. This may perhaps be associated with the freer drainage properties of the soils in the high rainfall areas; waterlogging was experienced on several occasions in the other soils.

(6) *Diseases*

Two, perhaps three, diseases of yams have attracted attention in recent years.

(i) *Leaf and stem necrosis*

This is attributed to a species of Colletotrichum and appears as spots on the leaves, immature or mature, and black areas on the young stems. Typically the necrotic areas rapidly enlarge, affecting first the more distal parts of the shoot system, ultimately killing the whole aerial portion of the plant. The necrosis does not appears to penetrate into the tubers and if the onset of the disease is late enough, e.g. November, it may be possible to harvest a modest crop; if the disease strikes earlier, however, the crop from affected plants are recognised early the fungus spreads rapidly, mainly downwind and the whole fields can be virtually wiped out. At pre ent control is by spraying the whole field with copper fungicides as soon as any diseased plants are seen.

A study of this disease is under way both in Barbados and in Trinidad; we hope that information will come forth as to the conditions leading to its occurrence and spread, and to effective means of control. An early report suggests that the disease is most severe in cultivars that mature early.

(ii) *Internal Spotting*

The flesh of the mature tuber, particularly towards the stem end, shows small brownish to black spots, often minute, but sometimes several millimeters across. These spots are nodular and may be cleanly excised from the tissues : they show no obvious connections with the vascular system. Under the microscope they appear to be made up of radiating groups of cells. So far there is no clue to their origin: no pathogenic organisms have been isolated from these areas, viruses or mineral deficiency have been suggested also nutrient imbalance associated with a higher degree of fertility of present-day soils. The Ministry of Agriculture has set up experiments to examine these and other possibilities, and an early observation suggests that the condition is most severe in yams that mature relatively late, e.g. White Lisbon.

(iii)

Possibly associated with the above is a general necrosis of the internal tissues of the tuber of the yam during storage, though it has certainly not been conclusively proven that the black spots develop into the large necrotic areas, nor is it, to the best of our knowledge, absolutely certain that the necrosis has ever appeared in areas completely free from skin lesions. Two years ago this necrosis seriously threatened the export industry, but in 1966 rigorous selection of tubers without skin lesions and from fields relatively free from "internal spotting" led to — or perhaps was merely coincidental with — virtually not problems of this kind.

(7) *Die Back*

In December and January the aerial parts normally die back: this is commonly supposed to be associated with maturing of the tuber. However, this is by no means certain. It may to some extent be associated with or accelerated by the handling the 'vines' receive when the cane is being planted—we do know that even quite young plants can be virtually killed by quite gentle handling. It may be associated with physical damage resulting from the tradewinds which usually re-assert themselves after the rainy season, about mid-December. It may be associated with late development of fungal diseases. No systematic observations have been made as the matter has seemed relatively unimportant, since the yams are to be reaped at about this time in any case. However, a late maturing yam (March or April), might enjoy an advantage on the export market, and an experiment was actually done with yams that had had their sprouting artificially delayed by Maleic hydrazide. These were planted in August; they grew well, but died off only 4 months growth (end of December), and produced only very small tubers.

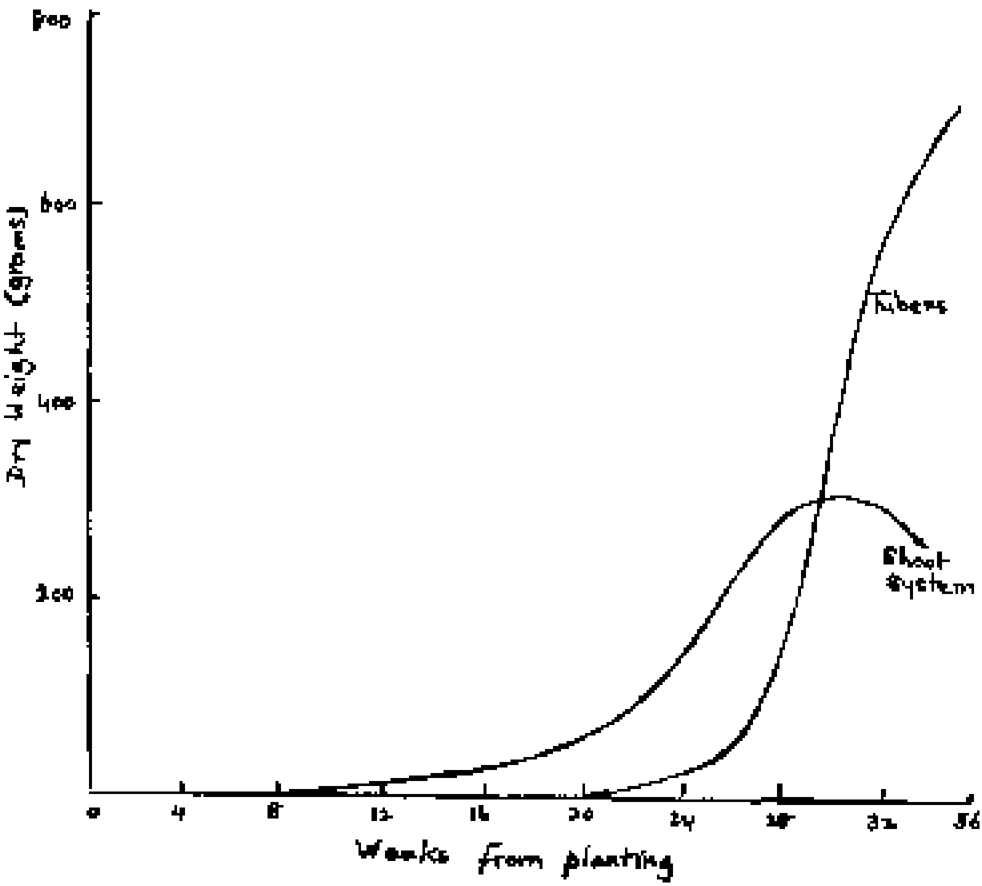
(8) *Deterioration of planting material*

It is commonly said among planters that continuing to plant cuttings from grown yams on the same plantation for several successive years leads to diminution of the crop, and it is normal practice to bring in planting material from some distant plantation every third or fourth year. There is no systematic experimental evidence that this deterioration does in fact take place, though a planter can often point out adjacent fields, one good and one bad, the good one having been planted with "outside" cuttings. Certainly the idea cannot be dismissed out of hand, but the explanation of such a phenomenon, in a small island where disease, for example, can hardly be isolated, is far from clear.

As we said at the start of this paper, little scientific attention has been paid to yams in Barbados until very recently. We have tried to show you some of the more important problems we have recognised—indeed there are many others—and to indicate where there has been progress, what has been done and what is being attempted.

Fig 1. YAMS 1965-66

DEVELOPMENT OF SHOOT SYSTEM AND TUBERS



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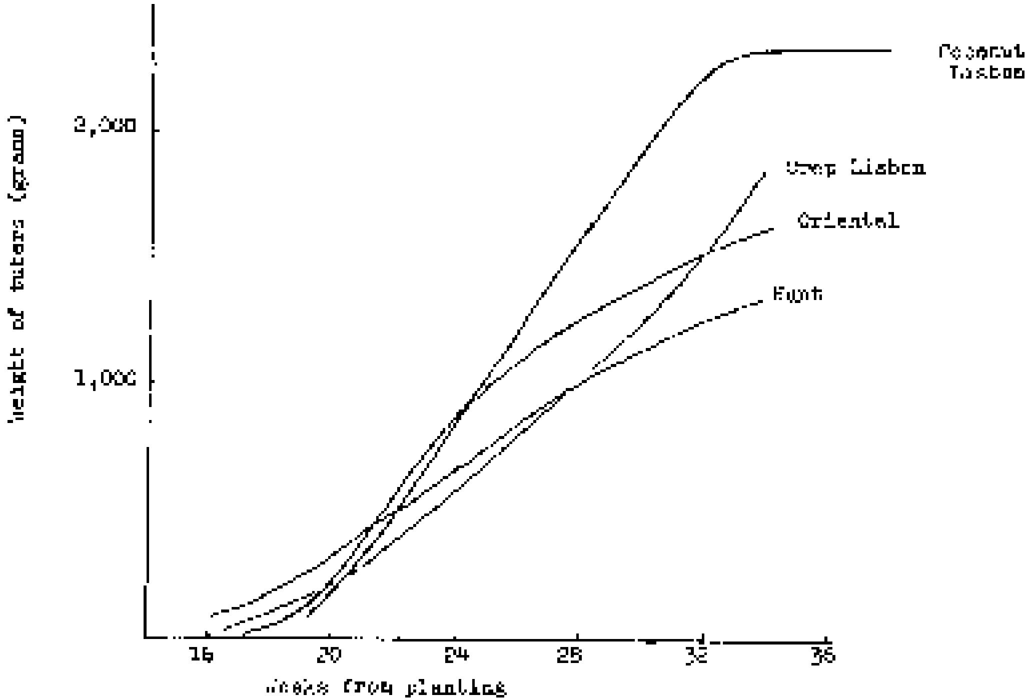
DEVELOPMENT OF FOUR CULTIVARS



DISCUSSIONS

Professor Harland :

In studies of the yield of crop plants it is desirable to try to specify the factors which are limiting, that is, what factors impose a ceiling on yield.

Mr. Gooding :

Yes, I could not agree more though it is somewhat difficult to establish these factors, when you are doing field experiments on plantations in which you have very little control over any of the factors except possibly fertilizing. We have no control over sunshine or water, and the best we can do under these conditions is to keep the fullest records possible, and when you study this year by year, locality by locality, you begin to get the idea that a certain factor becomes limiting at a particular level. We certainly bear this in mind. It is one of the tenets of my belief, so to speak, that limiting factors are sometimes a good deal more important than interactions that you look for.

We have had a case in point with corn, in which in one year we had quite a wide distribution of rainfall. We attempted to do fertilizer experiments and we had a rather interesting phenomenon that in regions of lower rainfall, there was absolutely no response to fertilizer, while in regions of higher rainfall we got a very substantial response. The conclusion being presumably, that rainfall was a limiting factor and when rainfall was a limiting factor the plant just could not grow enough to make use of fertilizer we put on it.

We had a rather similar experience last year, in which we had exceptionally high rainfall, and in the highest rainfall areas we got no response to treatments. In that case, excess water becomes a limiting factor. I think that's the sort of thing you have in mind Professor Harland, and you are really advising us all to keep these things in mind.

Dr. Martin :

Could you summarize recommended cultural practices with D. alata?

Mr. Gooding :

I will stick my neck out, but please regard these as very, very tentative and suitable only to the conditions under which I am experienced. If you are in sugar cane land and working as a catch crop, plant on ridges 5' by 2' 6" apart. Plant at the end of May, which is about the time the yam normally breaks dormancy and is also a week or two before the onset of the rainy season, fertilize with two to three hundredweight of sulphate of ammonia, plus 1½ cwt of sulphate of ammonia, plus 1½ cwt of muriate of potash at the appearance of second spices. Keep free from weeds and harvest when mature. Spray with Cupravit or some copper Fungicide.* If you see any attack of any plants appearing to die back for no apparent reason, it's probably Colletotrichum. Very rarely you may find an attack of Laphygma or something like that, which you will have to spray with Sevin, but this is extremely rare in yams in our conditions. If we were planting as a crop in its own right, I would recommend planting on ridge 2' 9" apart and the plants 3' apart in the ridge. We have a good deal of information about the effect of competition between plants.

Dr. Martin :

How do you harvest your yams?

Mr. Gooding

I regret to say, a man with a fork biting them out. I have been looking at the U.W.I. mechanical harvester to harvest sweet potato with great interest. I hope that if we grow small enough or round enough yams — the Coconut Lisbon as distinct from the White Lisbon — we may be able to use mechanical harvesting, breaking the ridge at least and throwing them out in the same way as you saw being done for potatoes

*Editor's Note — Colletotrichum appears to be insensitive to copper Fungicides. The organic fungicides are recommended under Trinidad conditions.

yesterday. But at present, they are harvested by hand, and we reckon that harvesting, rough cleaning, and transport and stacking in a shed in the plantation cost about one cent a pound.

Dr. Martin :

How do you control weeds waiting for yams to sprout?

Mr. Gooding :

We are trying pre-emergent herbicides such as Dacthal or Prometryne, but the normal commercial method is a woman with a hoe, who has so many acres to keep weed free. She is paid somewhere between $1.50 and $1.70 per acre per week and this is a time honoured method. Cost studies have indicated that with the current rates, it is almost exactly the same cost as spraying with Prometryne or Dacthal over a period of about 5 months.

Dr. Martin :

Have you had any experience of holding seed yams under various germination promoting conditions to shorten the time in the field before sprouting.

Mr. Gooding :

No, I have not.

Dr. Hon :

Virus- like symptoms have been reported on yam foliage in Barbados. Could Mr. Gooding say how widespread this condition is and whether it has any connection with deterioration in yield?

Mr. Gooding :

I personally have not yet seen this symptom, though I heard that it was reported in one plantation in St. Philip. I think Mr. Jeffers or Mr. Pilgrim could be asked to comment on this because I think they know more about it than I do.

Mr. Jeffers :

We have seen some symptoms appearing to look as if it could be a virus infection on the foliage of yams. At one stage, we thought that this could have been possibly associated with the internal spotting, but to date we have not been able to correlate anything. With regard to the internal spotting, this was noticed somewhere around 1965 when the yams were exported to the United Kingdom, but recently in carrying out a survey in Barbados, one planter reported that he noticed this condition about 30 years ago. We, so far, have had trends which seem to indicate that proper attention is paid to the selection of planting materials, that if you plant clean tubers that you are likely to harvest a clean product. More recently we have sent materials to the Tropical Products Institute in the United Kingdom, and they seem to think that our problem might be a virus one. We are not yet certain of this, but we are carrying out further investigations.

Mr. Pilgrim :

I just want to add one point to what Mr. Jeffers has just said. We are not at all certain about this problem of the internal spotting, whether it could or could not be a virus. One of the things is that we have noticed no symptoms on leaves, and therefore we are rather sceptical at the moment.

On the matter of spacing and yields, Mr. Gooding said that he had carried out very few experiments on this matter but we in the Ministry of Agriculture have also carried out experiments on spacing as related to yields, and our results are almost identical with his 5' x 5' spacing against 5' x 2'. The 5' x 2' gives almost double the yield.

Mr. James :

I was rather interested in your attempts to grow yams out-of-season as you might say. You said that the vines died off after 4 months which was around mid-December and this seemed to be around the same time that the normal crop would have matured. Elsewhere in that paragraph you hypothesised that the maturing of yams or the die back of yams might be associated with the trade winds which also came around mid-December. But you observed that this also coincided with the end of the rainy season and I was considering in Trinidad the die back of the normal crop of yams also seems to occur with the end of the rainy season, usually towards the end of January. I was wondering if there might be some association between the ending of the rainy season with the dying back of yam vines.

Mr. Gooding :

Yes indeed. I put forward all these points simply because we do not know and they do require further study. I'm glad to see that somebody has actually read the paper because these are points I did not make in my presentation but were actually in the paper. We did try, you see, yams in which sprouting had been delayed by the use of maleic hydrazide and they were planted about 4 months later than the normal yams. At that time they were beginning to sprout and we had hoped that we might carry them on and reap some later, but as I pointed out in my paper they died back at the same time as the yams planted 4 months earlier, giving less than one pound per plant. It could have been the onset of the dry season; it could have been the development of leaf disease, it could have been the drying effect of the trade winds which appear at about the same time as the rainy season ends.

EXPERIMENTS ON YAMS IN GUADELOUPE

— *by* —

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Since the establishment of the Research Institute for Tropical Agriculture and Food Crops (L'Institut de Recherches Agronomiques Tropicales et des Cultures Vivrieres or I.R.A.T.) in July 1963, work has been undertaken on yams as part of a programme of short term work with restricted aims, on vegetables, root crops, corn and other food crops.

Interest of yams in the French West Indies

The interest of this programme is justified within the general policy of crop diversification. This policy has been carried out for some years in these islands, in order to reduce the effects of an agricultural production that is too dependent upon the sugar cane and banana crops.

In the French Antilles, the yam is a traditional crop of primary importance. Local markets are far from being negligible because the vegetable tuber has remained popular not only with the small farmers, who produce it for their own consumption, but with the majority of Antillais. To these local outlets, one should add certain foreign markets, particularly in Europe, which are developing due to the presence of an increasing number of Antillais as well as to the growing attraction in these countries for tropical products. The yam seems fairly well placed to satisfy the new requirements, on the one hand because of the traditional taste for this crop of many Antillais farmers, and because of the adaptation of this plant to the different ecological regions of these islands, on the other hand. It seems quite possible to develop gradually from the numerous different types of this plant, new varieties satisfactory to the demand of new consumers, and adaptable to the special problems of storage and transport

Aims

Presently yams are nearly always manually cultivated by farmers in small areas where mechanization is not possible. Moreover, Martinique and Guadeloupe are crowded islands, and space for expanding cultivation is more and more limited. Therefore, the problem is to promote a type of cropping in lands suitable for mechanisation, keeping the methods of intensive cultivation and high yield which will allow the yam to compete with present monoculture. It is within this very practical framework that I.R.A.T. has been experimenting with yams for the last years

Collection

In 1964, an inventory of the main varieties which exist in Guadeloupe was made. This inventory dealt with the following *Dioscorea species*: *alata, cayenensis, rotundata, esculenta, trifida and bulbifera*, represented by about twently clones.

Seven varieties mainly belonging to the *alata* and *cayenensis* species, coming from Dahomey, were also studied in 1964.

This collection was continued in 1965 and 1966. Some new introductions were made, such as the cultivar "Barbados", from Trinidad. Two serious hurricanes in 1964 and 1966, two hurricanes in three years, unfortunately damaged these collections, and hindered to a great extent the results.

However, these collections did allow us to achieve the following:

Develop some morphologic characteristics which will make possible identification in the field,

Estimate the length of the vegetative cycles, the periods of germination, and the length of dormancy,

Compare the sensitivity of various clones to insects and diseases,

Have an early estimation of yield potential,

Better understand the main qualities and defects of the tuber in each variety.

By way of example, we present some of the results obtained from our study during the last three years:

Simplified key based on simple morphological characteristics determined in the fields.

This key seemed necessary to us, considering the absence of sufficient local data: it has just one purpose, to help the layman and all those concerned with yam culture in every day practice.

The principal criteria are easy to observe at any period of the plant's vegetative cycle:

- twisting of the stem,
- Presence or absence of thorns,
- number of leaf lobes,
- intensity of pigmentation.

The secondary criteria allow more precise differentiations between species:

- presence or absence of bulbs,
- colour of the pulp,
- shape of the tuber,
- shape of the leaves,
- number of the veins.

Germination.

Most of the observed yams germinate between March and June, in this order of precocity: *rotundata, esculenta, trifida, alata*. For an identical group, the dates of germination are quite close. However, we must point out the germination in March of an *alata* yam from Dahomey. It follows that, in spite of the possibilities of conservation of certain yams, the production of this tuber in Guadeloupe is quite irregular all the year long. An "uncycling", for example, by means of ethylene chlorhydrin as tried in Trinidad (Campbell, et al 1962), seems to be very useful if production is to be regularized.

Yields.

It is important to distinguish from the beginning several types of yams :

Yams particularly appreciated by the consumers: In the first group, we especially study not only the constituents of the yield, but also the differences which may exist between the clones and the susceptible factors which can modify them concerning:

- the exterior appearance of the tuber (regularity of shape, appearance of cork, absence of rootlets);
- the taste qualities (texture, fibre, bitterness);
- the qualities in connection with possibilities of storing and transportation.

Yams of little or no use for human consumption: but its high productiveness, even its hardiness, may be considered to furnish perhaps a base for animal foods.

For these sorts of yams, the searched-for qualities in priority are the high yield in dry material, the ease of culture and harvest, the possibility of conservation, the absence of toxicity, and the appetizing qualities.

Here are some obtained yields at various places in Guadeloupe, in 1964 and 1965, in areas of 100 to 1000 square meters.

- Pacala *(D. alata)*. . . . . 15 to 20 T/Ha
- White Cush Cush *(D. trifida)* . . . 15 to 20 T/Ha
- Sweet Cush Cush *(D. esculenta)*. . .25 to 30 T/Ha
- "En bas bon" *(D. alata)*. . . . . . . 30 to 40 T/Ha

(Metric ton per Hectare).

Fertilizer response

The results given below (Tables 1 and 2) show the importance of mineral manure upon *D. trifida*. These two tests have been made on recent volcanic soils in Basse-Terre (Guadeloupe).

Table 1. The response of D. trifida to mineral and organic fertilizers with staking. (Yields in metric tons per hectare).

	10 T/Ha Organic Manure	*Without Manure*	*Mean*
500 Kg/Ha 10-10-20	21.1	17.5	19.3
Without mineral fertilizer	17.3	14.5	15.9
Mean Yield	19.2	16.0	

Table 2. The response of D. trifida to mineral and organic fertilizers in the absence of stakes. (Yields in metric tons per hectare)

	15 T/Ha Organic Manure	*Without Manure*	*Mean*
700 Kg/Ha 10.10.10	21.2	20.0	20.6
Without mineral fertilizer	16.5	15.3	15.9
Mean Yield	18.8	17.6	

In both cases, we note:

- *A significant difference* between the plots which have been mineral fertilized, and those which have not.
- *An insignificant difference* between the plots which have been organically and those which have not.

For the second trial, for example, the increase in yield due to the mere mineral manuring (4,7 T/Ha) comes, at the present cost of this yam in Guadeloupe, to a financial profit greater than 8 (that is, the relation between the increase in value of the crop, and the increase in expenses resulting from using fertilizers).

It is interesting to note the similarity of the obtained results, in spite of the important difference beween the formula of mineral manure applied.

Finally, we must note that the first trial was obtained by staking the yams, and the second one obtained without staking.

Staking:

We treated this problem more particularly with *D. alata*, in Guadeloupe, with a brown soil of recent volcanic origin. In this test, we associated three ways of semi-mechanical preparation of ridges of earth. Besides, on the unstaked plots of land, sugar-cane straw was spread on the ridge after the planting.

There results, (Table 3) some of which may appear to be surprising, would merit further study.

Table 3. The effect of type of ridge and mulching on yield of D. alata. (Yield in metric tons per hectare).

Tillage / *Staking*	*Ridging only*	*Ridging on furrow*	*Ridging on furrow with cane leaves*	*Mean*
Mulching with cane leaves No staking	22.5	20.0	22.4	21.6
No mulching. No staking.	22.3	18.1	20.2	20.2
Mean Yield	22.4	19.05	21.3	

One does not observe a significant difference between the treatments. It should be interesting to prove such a result, to which one can try to explain the following, in other situations: the leaf development, much reduced in unstaked soils, is sufficient to give as high a yield in these plots as in the staked ones, it seems that, for the whole of the culture, there must exist a yield limitation (the law of minimum). In the present case, the reasons why the development of the tuber is limited may come from a soil-tillage that is too much superficial, as well as a quick soil-compact and silting which characterize such soils.

Independent of the economic advantage of the discontinuance of staking in such cases, we will see, more so, that mulching on the surface does not appear justified, sometimes, for the culture of this variety of alata.

Control of weeds:

Controlling the weeds in unstaked yam culture is very important, for the following reasons:

- Length of culture period
- Importance of period when plant does not properly cover the ground
- Rather poor control of the weed by the yam itself, particularly certain types of alata
- Important competition between yam and weeds, concerning the use of water and fertilizers.

To the above reasons can be added the higher and higher cost and shortage of the French West Indian labour.

A way to partially control the weeds consists in planting more densely, which of course modifies the average weight of the yams (often limited by commercial imperatives), and the net obtained yield once deducted the weight of the plants. Under this final aspect, the optimum density is often far from the one that would give the best weed control.

The mulching process is equally interesting for controlling weeds. However, on soils where surface tillage while cultivating seems necessary for making easier inner aeration and drainage of the soil, mulching can be harmful as it makes difficult such a soil cultivation. This may explain the following results Table 4 obtained at Basse-Terre (Guadeloupe):

Table 4. (A pre-emergent weedkiller was used for the whole of the test). The effect of mulching on yield of yams at Basse-Terre (Guadeloupe).

	Cane leaves Mulch	*Bare Soil*
YIELD (in T/Ha	14.2	19.2

(Significant difference)

Of that which concerns weed control by chemical weed-killers, the utilization of the following herbicides has been compared in pre-emergency:

Prometryne ....2 Kg/Ha		Spread after planting, avoiding full pulverization on the tops of the ridges where the yams are planted.
Diuron ....2, 4 Kg/Ha		
Atrazine ....2, 4 Kg/Ha		

Atrazine showed a slight phytotoxicity in dry and clayey areas.

The period of effective control by atrazine (total control : 6 to 7 weeks) appeared higher than for the two other weed-killers.

The use of these weedkillers reduces the frequency and the time of weedings. Atrazine took 15% less weeding time compared with the two other weedkillers.

For the same number of weedings done on treated and non treated plots, the yields obtained Table 5 on plots treated with weedkillers were higher than on the untreated plots.

Table 5. The effect of chemical weed control on yield of yams.

		Yield T/Ha
A)	Prometryne	18.6
B)	Diuron	18.6
C)	Atrazine	16.1
D)	Nothing	13.2

No significant difference between A, B and C.

Conclusion.

The yam is a plant for which interest in the Antilles is far from being neglected. Within a short period of time, the development of its culture supposes first on a profound knowledge of existing vegetable material and its adaptation to the diverse West Indian ecologies. It supposes further on the choice of varieties to promote, and the tuning of all techniques to grow this yam, in moreso important areas, with higher profits, at the lowest possible prices.

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REGENERATIVE ABILITY TRIALS ON TUBER PIECES OF *DIOSCOREA COMPOSITA* IN MEXICO

— *by* —

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Rhizomes of *Dioscorea composita* Hemsl., a sapogenin bearing yam, have been used during the last 15 to 20 years as the raw material for the synthesis of cortisone and steroidal hormones medically useful for different diseases and as ovulatory regulators in man and other animals. Up to now Mexico has been the main source of this raw material. It is only in the last few years that India and China have produced steroidal hormones isolated from *Dioscorea deltoidea* and several *Solanum* species.

Other sapogenin-bearing species of the genus *Dioscorea* have been used or are in use at present in Mexico; *D. floribunda, D. spiculiflora, D. mexicana* named in order of importance.

Abundance or sapogenin content of these species is lower than that of *D. composita;* herein after we will refer exclusively to this species.

D. composita, whose comon name is "barbasco", has its main area of distribution and abundance in the lowlands of the Gulf Coast of Mexico in areas with a hot-humid climate (the A type of climate in Koeppen's climatic classification). The best soils for the growth of *D. composita* are red, yellow or brown, deep latosolic or lateritic with a fairly good drainage, formed from volcanic materials and with pH values ranging from 5 to 6. The native vegetation in these conditions is in most of the cases a high evergreen forest with dominant *taxa* such as *Terminalia amazonia, Callophyllum brasiliense, Dialium guianense, Guatteria anomala, Swietia panamensis,* and similar species.

The productivity of *D. composita* in natural conditions ranges from 200 to 500 kg/Ha to 4 to 6 Tons/Ha. Average yields range from 1 to 2.5 Tons/Ha. The amount of Diosgenin present in the rhizome, which is the product that gives value to the tuber, is affected quite drastically by environmental factors. Water content of the soil is one of the main factors that produces variability in the Diosgenin content. Genetic variation could exert influence also on the tuber's sapogenin content. Percentages of Diosgenin in tubers of *D. composita* averages, in natural conditions, between 4.5 and 5% of the fresh weight. The average production per plant is close to 2.5 to 3.4 kg. The highest yield found for a single rhizome was a bit more than 250 kg.

Barbasco is exploited as a wild plant in Mexico, and hence is considered as a natural renewable resource rather than a crop. In regard to its value, barbasco occupies the second place, after timber, among the nation's forest products. The total amount extracted in 1966 was 15,000 metric tons of fresh rhizome. The value of a metric ton of rhizome, (fresh weight), with an average content of sapogenin between 4.5 and 5.0% is approximately the equivalent of $30.00 U.S.

Soon after the initiation of exploitation in Mexico, the Mexican Government through its National Institute of Forestry Research, established a Commission for the study of ecology of this plant.

The ecological studies have involved the careful analysis, description and characterization of the main plant communities in the Gulf coastal tropical regions of Mexico, the productivity of *D. composita* within each plant community and each geographical area, and the effect of the anthropogenetic activities upon such productivity.

A general picture of the ecological studies concerning *D. composita* was presented by Gomez Pompa *et al.* (1964). Sarukhan, (1967), elaborated a thorough analysis and discussion of the method employed in those studies.

The basis of all the ecological field work lies on the definition and delimitation of units in a given geographical area. These have been designated as *ecological units* (Sarukhan, 1967) These ecological units are separated by means of both the physiognomy and the floristic composition of the communities and always correspond with a *vegetational type*. (Miranda and Hernandez X., 1964).

Vegetation maps are made delimiting these ecological units showing the geographical distribution of the communities that include or exclude the presence of *D. composita*. These ecological units include primary as well as secondary vegetation produced by the anthropological activities

Once the vegetation maps for different areas have been elaborated, intensive random samplings are made to determine the productivity of *D. composita*. Productivity for both primary and secondary stages of vegetation and hence for the vegetation type to which those stages belong is calculated. The addition of the productivities of different vegetation types, gives the approximate productivity potential of a given georgraphical area.

In theory, one would expect that higher productivity levels should occur in the primary forest. But in our conditions, highest productivity levels are founded in secondary stages some 15 years of age.

This is the case when peasants fell the original forest or high vegetation for the cultivation of his crop. While ploughing the field, a frequent fragmentation of many of the *Dioscorea* tubers present in the ground occurs. This is a very efficient way of stimulating vegetative propagation. With this increase of individuals of *D. composita* one needs only to allow time to get a very high production in that abandoned area. It is necessary to say, however, that if shifting agriculture permits and even stimulates the productivity of *D. composita*, permanent agriculture, on the other hand eliminates its presence quite drastically.

It is our feeling that *D. composita* occupies at present a privileged position in relation to most root crops or other crops, since this is one of the few species in which a good deal of its environmental requirements are known in the wild and its relationships with the physical and biotic components are fairly well established before it becomes a widely distributed cultivar.

Most of the problem of cultivation of *D. composita* have been studied and solved (Martin et al, 1966). Its cultivation in a commercial scale is possible.

Whether or not *D. composita* will become a very important economic crop, is a matter that falls beyond the scope of this paper. However, a point that we would like to stress here is that the basic knowledge of the ecological relationships and requirements of any species at the wild level would help considerably in any attempt of domestication of such a species.

Regeneration Studies

Although *D. composita* has a fairly good index of self-regeneration both by tuber pieces left in the ground or by seeds, we became interested in understanding as much as possible the dynamics of its regeneration. We were looking for a method as natural as possible to induce the repopulation of this species. Our main experiences concern the ability of regeneration of different parts of the tuber in experimental conditions, the characteristics of seed dispersal and the study of viability of seeds in natural conditions.

The following trials have been carried out in an area with deep, red lateritic loamy-clay soils, of alluvial origin, with a fairly good drainage (Red Lateritic Soils, Semimaturm; Cuanalo, 1965).

A. — *Experimental objectives.*

The trials conducted had the following objectives:

a) to establish the effects of disturbance of the vegetation upon the regeneration and the growth of barbasco tubers;

b) to determine a quick and effective method of regeneration;

c) to know which tuber pieces sprout first and/or regenerate best;

d) to determine the best season for the initiation of regeneration practives and the optimum depth of planting; and

e) to obtain information concerning increase in tuber weight.

B. — *Materials and Methods*

Tubers of plants from an area contiguous to the experiment, were collected at random for the trials, one or two days before the planting of the experiment. Digged rhizomes were stored in a fresh, shaded place.

Three parts of the rhizome were used in all trials; the area of emergence of the vines or crown: middle portions of the tuber and terminal or tip pieces. Two sizes of each of the three portions were assayed: 5cm. (2 in.) and 10 cm. (4 in.). Treatments were as follows:

T 1 — Crown piece 5 cm. (CP 5)
T 2 — Crown piece 10 cm. (CP 10)
T 3 — Middle piece 5 cm. (MP 5)
T 4 — Middle piece 10 cm. (MP 10)
T 5 — Terminal piece 5 cm. (TP 5)
T 6 — Terminal piece 10 cm. (TP 10)

The experimental design used was random plots, with 20 tuber pieces per plot 1 m., (40 in.) apart from each other. Plots were separated 2m (80 in.) on all sides. Total number of propagules in a experiment was 480.

Tuber pieces were cut to the appropriate size (5 or 10 cm.) with a machete only a few hours before planting. Holes were made and the tuber pieces covered with a shovel-like instrument ("coa") at a depth of 10 — 15 cm. (4-6 in). No fungicide or any other preservative was used.

Four different trials were established to determine the influence of the disturbance of the vegetation and the different season of planting upon the regeneration of tuber :

Experiment 1. — *Planting in a denuded area, during the dry season.*

Experiment 2. — *Planting in secondary vegetation 3-5 m. high (2-3 years old), during the dry season.*

Experiment 3 — *Planting in secondary vegetation 15-20 m. high (15 years old), during the dry season.*

Experiment 4. — *Planting in secondary vegetation 3-5 m. high during the rainy season.*

The first three experiments had exactly the same treatments and the same experimental design of random plots. The fourth had different treatments in random plots.

Results

Experiment 1. — *Planting in a denuded area.*

An area with secondary vegetation 2—3 years old with dominant species such as *Waltheria brevipes*, *Heliocarpus donnell-smithii* and *Bixa orellana*, was selected and cut to obtain a bared area, but natural vegetation was allowed to grow after planting. The experiment was planted in December 1960 and harvested December 1961. Seven observations were made between these two dates. Results of Experiment 1, are presented in Tables 1, 2 and 3.

Table 1. Number of live plants at harvest, planted in a denuded area. Plants 1 year old originating from different tuber pieces. Original number of propagules per plot: 20.

Treatments[a]	Replicates				Total of Treatments
	I	II	III	IV	
CP5	5	2	8	4	19
CP10	9	13	6	5	33
MP5	7	5	7	7	26
MP10	7	9	7	5	28
TP5	11	12	9	13	45
TP10	14	13	5	9	41
Total of Replicates	53	54	42	43	192

[a]See text for explanation of treatments.
C (correction of mean): 1536.
Sum of squares of treatments: 118
Sum of squares of replicates: 20.33
Total sum of squares: 246.

Table 2. Analysis of Variance of data in Table 1.

Source of Variation	Sum of Squares	Degrees of Freedom	Variance	F. Calc.	F Tables 0.05	Significance
Treatments	118.00	5	23.600	3.2878	2.90	+
Replicates	20.33	3	6.776	0.9439	3.29	
Error	107.67	15	7.178			
Total	246.00	23				

+ Significant difference between treatments.

Table 3. Least significant differences of Experiment 1.

L.S.D. at 0.05 level: 16.146

Treatment	Totals of treat.	Diff.	% Sprouting	Significance[a]
TP5	45	-	56.25	a
TP10	41	4	51.25	ab
CP10	33	8	41.25	abc
MP10	28	5	35.00	bc
MP5	26	2	32.50	bc
CP5	19	7	23.75	c

[a]Treatments that do not have letters in common are significantly different at p:0.05, according to Duncan's method, (1955).

Treatments that sprouted first were CP5 and CP10, (Crown pieces, 5 and 10 cm. size); however, crowns of 5 cm. presented the lowest number of living plants at harvest, probably due to the amount of reserves present in that part of the rhizome. 211 out of 480 propagules were lost by rotting. Highest decay was found in middle pieces.

Experiment 2. — *Planting in secondary vegetation 3-5 m. high (2-3 years old).*

The area selected for this experiment was contiguous to that of Experiment 1, with similar soil properties but different vegetation coverage, with dominant *taxa* such as *Heliocarpus donnell-smithii, Apeiba tibourbou, Cochlospermum vitifolium, Bixa orellana, Waltheria brevipes, Clibadium arboreum* and*Luehea speciosa.*

Treatments and experimental design used was the same of that used in Experiment 1, but each tuber piece was weighed

The experiment was planted in February, 1961 and harvested December, 1965 Six observations were made between these two dates consisting in counting the number of sprouted propagules. Results from this experiment are presented in Tables 4, 5, 6 and 7.

Table 4. - - Number of live plants at harvest planted in a secondary vegetation 3-5 m. high Plants 46 months old originating from different tuber pieces. Original number of propagules per plot .20.

Treatments*	Replicates				Total of Treatments
	I	II	III	IV	
CP5	2	3	3		8
CP10	2	1	4		7
MP5	–	5	1	3	9
MP10	1	3	1	3	8
TP5	4	5	11	3	23
TP10	9	2	4	2	17
Total of replicates	18	19	24	11	72

Table 5. Analysis of Variance of data in Table 4.

Source of Variation	Sum of Squares	Degrees of Freedom	Variance	F. Calc.	(F. Tables) 0.05	Significance
Treatments	53.00	5	10.60	1.79	2.9	+
Replicates	14.33	3	4.77	0.80		+
Error	90.67	15	5.91			
Total	158.00	23				

+ No significant difference between treatments nor between replicates.

Results obtained at almost four years of growth contrast with those obtained at 1 year. One of the observations between planting and harvesting was analyzed in an attempt to locate the cause of this difference Table VI shows the analysis of variance of data obtained in an observation two years after the planting.

Table 6. Analysis of Variance of data obtained in an observation of number of sprouted propagules two years after planting in secondary vegetation, 3-5 m. high.

Source of Variation	Sum of Squares	Degrees of Freedom	Variance	F. Calc	F. Tables 0.05	Significance.
Treatments	120.00	5	24.00	6.93	2.90	+
Replicates	4.50	3	1.50	0.44	3.29	
Error	52.00	15	3.46			
Total	176.50	23				

+ Significant difference between treatments.

Table 7 Least significant differences for the Analysis of Variance in Table 6.

L.S.D. at 0.05 level: 11.203

Treatments	Total of treat.	Diff.	% Sprouting	Significance+
TP5	34	–	42.50	a
TP10	28	6	35.00	ab
MP10	17	9	21.25	bc
CP5	14	3	17.50	cd
MP5	13	1	16.25	cd
CP10	8	5	10.00	cd

+ Treatments that do not have letters in common are significantly different.

Best treatments at 2 years after planting were again terminal parts of both sizes. Crown parts showed a consistent tendency of prompt sprouting just after planting but a poor survival. Only 15% of the original propagules planted remained alive until the fourth year. Highest losses were found in treatments involving middle and crown tuber pieces.

Experiment 3. — *Planting in secondary vegetation 15-20 m. high (15 years old).*

A site with an advanced secondary vegetation was selected located 25 m. from preceeding experiments. The site had the same soil properties and topography as the sites of Experiment 1 and 2. Dominant species here were *Terminalia amazonia, Apeiba tiborbou, Luehea speciosa* and *Cordia alliodora*. Trees were 15-20 m tall and the surface of the soil was almost completely shaded and covered with a thick layer of humus. Vegetation was not distributed for the establishment of the experiment.

The date of planting was February 1961 and of harvesting December 1965. Between planting and harvesting 5 counting of sprouted propagules were made. The same treatments and experimental design as in the preceeding experiments were used. Tables 8, 9, 10 and 11 show results and statistical analysis.

Table 8. — Number of live plants of D. composita at harvest. Propagules planted in an secondary vegetation, 15-20m. high. Plants 46 months old originating from different tuber pieces. Original number of propagules per plot: 20.

Treatments°	Replicates				Total of treatments
	I	II	III	IV	
CP5	2	–	–	3	5
CP10	8	1	1	1	11
MP5	–	2	–	1	3
MP10	1	2	3	–	6
TP5	7	1	5	5	18
TP10	3	2	1	3	9
Total of replicates	21	8	10	13	52

°See text for explanation of treatments.

C (correction of mean): 112.66
Sum of squares of treatments: 36.34
Sum of squares of replicates: 16.34
Total sum of squares: 109.34

Table 9. — Analysis of Variance of data in Table 8.

Source of Variation	Sum of Squares	Degrees of Freedom	Variance	F. Calc.	F. Tables 0.05	Signif.
Treatments	36.34	5	7.26	1.92	2.90	+
Replicates	16.34	3	5.44	1.43	3.29	+
Error	56.66	15	3.78			
Total	109.34	23				

+ No significant difference between treatments nor replicates.

As in the case of Experiment 2, no difference was founded of regenerative ability among the different parts of tubers of *D. composita* almost 4 years after planting. Table X shows the analysis of Variance of data obtained in an observation two years after planting.

Table 10. Analysis of Variance of data observed on number of sprouted propagules of D. composita two years after planting in secondary vegetation, 15-20 m. high.

Source of Variation	Sum of Squares	Degrees of Freedom	Variance	F. Calc.	F. Tables 0.05	Signif.
Treatments	233.84	5	46.76	4.84	2.90	+
Replicates	23.17	3	7.72	0.80	3.29	
Error	144.83	15	9.65			
Total	401.84	23				

– Significant difference between treatments.

Table 11. — Least significant differences for the Analysis of Variance in Table 10

L.S.D. at 0.05 level: 18.71

Treatments	Total of treat.	Diff.	% Sprouting	Significance+
TP10	44	—	55.00	a
TP5	33	11	41.25	ab
MP10	29	4	36.25	ab
CP10	21	8	26.25	bc
MP5	10	11	12.50	cd
CP5	9	1	11.25	cd

+ Treatments that do not have letters in common are significantly different.

Terminal pieces 10 cm. size again showed the higher regenerative ability. Middle pieces showed a similar regenerative ability as terminal pieces 5 cm. in length. The middle and crown pieces of the tuber gave the worst response. In Experiment 3 only 10.8 percent of the total initial population survived. Almost 95 and 90% respectively of the propagules of treatments with middle and crown pieces, decayed at fourth year.

Experiment 4. — *Planting in secondary vegetation, 3-5 m. high during the rainy season.*

A fourth Experiment was planned to observe the periodical increase in weight of tubers. Treatments with terminal and crown pieces only 10 cm. in length of *D. composita* were programmed to be harvested 6, 12, 18 and 24 months after planting. A new variant was introduced in this experiment. to plant the propagules in the middle of the rainy season. The high moisture of the soil caused an almsot complete lost of propagules due to decay. No analysis of results was made.

Analysis of weight increase of D. composita tuber pieces.

The individual weight at planting and harvest of each propagule used in Experiments 2 and 3 was analyzed. However, all treatments except two showed a loss in weight at harvest Almost all the surviving plants had considerable gains in weight and increase in tuber length was quite noticeable.

Difference in weight (gain or lost) of tuber at harvest are presented in Table 12.

Table 12. — Differences in weight at harvest of propagules of D. composita planted in secondary vegetation (3-4 years old). Age of plants at harvest : 46 months.

Treatment	Difference in weight (neg. values)	Diff. bet. treatments	Significance +
TP5	1.528	—	a
TP10	4.225	2.697	ab
CP5	4.245	0.020	ab
MP5	7.090	2.845	ab
CP10	9.605	2.515	b
MP10	19.360	9.755	c

+ Treatments that do not have letters in common are significantly different.

Table 13. — Differences in weight at harvest of propagules of D. composita planted in a secondary vegetation (15-20 years old). Age of plants at harvest: 46 months.

Treatment	Difference in weight (negative values)	Diff. bet. treatments	Significance +
TP5	0.030	—	a
CP5	3.765	3.735	b
TP10	4.100	0.335	b
MP5	7.620	3.250	c
CP10	9.775	2.155	c
MP10	15.610	5.835	d

+ Treatments that do not have letters in common are significantly different. Middle detrimental values are found in terminal pieces both of 5 and 10 cm. in length. Highest detriments were found in treatments with middle pieces. This difference could be due in part to the wide difference in weight between the light terminal parts and the bulky middle pieces.

Discussion

A definite behavioral pattern was found in the tests of regeneration ability of tuber pieces of *D. composita*. Terminal pieces, where a great amount of meristemal tissue is found, presented a consistent high regenerative capacity from the first year of growth. Although crown pieces sprout very promptly, they do not have the capacity to survive probably due to the lack of reserves. Middle pieces, although containing a good amount of reserves are very susceptible to decay due to their relative lack of meristemal tissues and the large area exposed to fungus and nematode invasion.

A marked difference in the number of surviving plants was found among the three different experiments at the end of the first year; number of surviving plants decreased as the age of secondary vegetation increased, e.g. the denuded area gave a higher number of survival than the young and advanced secondary vegetation. The young (3) 4 m. high) secondary vegetation had more live plants at harvest than the site with advanced secondary vegetation (15-20 m. high).

Obviously a strong competitive factor produced by the native vegetation plays a very important role in the regenerative ability of *D. composita* tubers. This phenomena was observed also by Cruzado, Delpin and Roars, (1964) who found that all live supports sharply reduced *Dioscorea* yields. *Melinis minutiflora* Beauv., the molasses grass," showed a very interesting kind of root inhibition with *D. composita* propagules. Tuber pieces growing under an area heavily covered by this grass remained alive with the same original size and weight during the almost four years of the experiment.

An abundant wild rodent, the "tuza", (*Geomyces sp.*) affected to some degree the planted population of *D. composita* propagules. However, highest loss was produced by decay of the tuber on the ground. The rainy season was very unfavourable for the planting of any *D. composita* tuber fragment.

The results of the experiments conducted show that reduced regeneration practices with *D. composita* tuber pieces are not favourable. Natural regeneration from abandoned terminal pieces of tuber seems to be more successful. Observations on the influence of the dept of planting of propagules and on the periodical gain in weight are needed to obtain a more complete picture of the regenerative ability of *D. composita* tuber segments.

SUMMARY

Tuber fragments of *Dioscorea composita* were used to observe their regenerative ability. Crown, middle and terminal pieces of the tuber were used and two sizes of each part tested. To determine the effect of the vegetation on establishment, — propagules were planted in three stages of secondary vegetation. Duration of experiments was from 1 to 4 years. At four years no significant difference among the treatments was found. However, at the end of the first and second year, terminal parts presented the highest regenerative ability. Crown pieces sprout promptly but do not survive after few months. Middle pieces are very susceptible to decay. Competition by the native vegetation showed to be an important limiting factor — for practices aimed at increasing population. A sketch is — presented of *D. Composita* in its natural environment in Mexico, derived from the ecological studies conducted to date.

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DISCUSSIONS

Dr. Richardson :

I have two questions. First, do you refer to **Dioscorea composita** as an individual specie or a combination of a number of species of the wild material ?

Dr. Sarukhan :

It is one specie

Dr. Richardson :

The second question. Did I understand you to say that you felt that the environmental ecological knowledge was sufficient at this stage to put this particular specie under cultivation as a crop ?

Dr. Sarukhan :

No. My feeling is that ecological knowledge of the requirement of a specie is a very good help to take the specie to domestication level. It's by no means enough to take the specie to a domesticated level but it helps very much to understand the requirements of the specie, though a knowledge problem of these relationships will give you a better picture of the likely problems in domestication

Dr. Shrum :

If I understand you correctly, there are tips left in the ground after harvesting operations by wild collectors. Do you feel that these tips will recover, produce plants and continue to supply a root source in Mexico ? And I would like to ask you what the price of the root is in Mexico for the dry root at the present time.

Dr. Sarukhan :

The residues of the tuber pieces in the ground is not a reliable way of ensuring regeneration. Of course we must remember that regeneration by seeds is also quite effective.

The price is variable because it depends very much on the season of harvesting. It is about 300 pesos per ton fresh weight.

Dr. Martin :

I would like to ask if the experience you gained over the years working on **Dioscorea composita** leads you to believe that there are strong differences in the sapogenin content and the tuber size from area to area. Are these differences likely to be genetic rather than environmental ?

Dr. Sarukhan .

We have found strong differences in the sapogenin content. One of the reasons for this difference is the water content in the soil. We have thought about this problem of ecological influence or something more related to the genetic problems of the species. We have no finished studying biosystematics of **Dioscorea composita**, but we suspect that there is quite a strong genetic variation in the species, We think that this genetic variation, together with the ecological variation, adds to the observed variability

SOME EXPERIMENTS WITH POTATOES (SOLANUM TUBEROSUM) IN TRINIDAD 1963-4

— *by* —

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Imported foodstuffs have fulfilled an important role in the diet of the people of Trinidad and Tobago and considerable savings of currency could be made by utilising more effectively the natural resources of the country and producing more food locally.

One of the crops which has been increasing in its importance is the potato and the value of imports of this crop rose from $ WI 989,665 to $ WI 1,517,725 during the period 1953-59.

There are two possible ways of cutting this import bill either by producing alternative indigenous root crops more economically or by attempting to grow some part of the imported crop in Trinidad.

Thus Gooding imported seed tubers of various cultivars and tested them during the period 1959-61. His initial success (Gooding 1961; 1964) led to the belief that it would be possible to grow potatoes commercially, at least during the dry season when climatic conditions were as favourable as possible for the crop. Gooding also demonstrated the importance of adequate irrigation in the growth of the potato during the dry season.

However, before a proper assessment of the potato as a commercial proposition could be made, certain factors had to be examined. The spacing which Gooding had used in his experiments seemed too wide, a fertiliser application had to be pre-determined and the irrigation regime needed investigation. Only then could an assessment be made of the feasibility of growing the crop commercially.

EXPERIMENTAL (1963)

It had been hoped to investigate irrigation regimes for the crop as a matter of priority but unfortunately equipment was not available to allow the irrigation of small plots and so this was abandoned. It was decided therefore to investigate the effects of a closer spacing of the crop using three of Gooding's better cultivars, maintaining soil moisture as close to the optimum as could be achieved, and also to determine the optimum fertiliser dressing for the crop under Trinidad conditions.

Gooding in previous trials has used an inter-row spacing of 3 ft with an intra-row distance of 1ft between setts. It was considered that this was too wide and so this spacing was compared with the more normal 2.25 x 1ft. Three cultivars were used at each spacing making six treatments in all and these were arranged in a randomised block design with four replicates. The cultivars used were "Alpha", "Eigenheimer" and "Patrones"; the seed tubers being obtained from Holland.

The site of the experiment was cultivated and then ridged. Each plot had a distance of either 3ft or 2.25 ft between the crests of the ridges. Fertiliser was added to the furrows by hand at a rate of 100 lb/acre of each of N, P_2O_5 and K_2O as sulphate of ammonia, super-phosphate (45% P_2O_5) and muriate of potash respectively. The plot size was 810 sq. ft.

The setts were planted 1ft apart in the furrows and were covered by splitting the ridges. Irrigation was applied at weekly intervals, the amount of water applied was varied to replenish the deficit between potential evapo-transpiration (calculated by the Thornthwaite method) and rainfall. Planting took place on 21.1.63 and harvesting approximately 90 days after. Routine sprays were used to combat *Alternaria solani* but disease incidence proved not to be a problem.

At intervals of 14 days throughout the trial two samples, each of five adjacent plants, were removed from each plot. These samples were separated into leaf, stem, root and tubers. The various plant parts were weighed and samples taken for dry matter determination. Net assimiliation rates (E_W) were calculated for the different varieties at the different spacings. Leaf weight was used as the basis for the calculation of E because no way of assessing leaf area was available.

Results

The total yields of tubers at harvest are given in Table I.

Table I Total yield of tubers at harvest (tons/acre)

Spacing / *Cultivar*	3 x 1 ft	2.25 x 1 ft	Mean
	±0.400 (3)		±0.283 (1)
Patrones	8.084	9.762	8.923
Alpha	6.762	8.618	7.690
Eigenheimer	7.082	8.431	7.757
Mean	7.309	8.937	8.123
	±0.231 (2)		

It can be seen from Table I that yield per acre was increased by the closer spacing and also that "Patrones" out-yielded significantly both "Alpha" and "Eigenheimer".

The pattern of the build up and decline of leaf weight and tuber bulking is illustrated in figure 1 for the cultivar "Patrones". The other cultivars were similar and diagrams have therefore been omitted.

The E (E_W) for all cultivars at both spacings are presented in Table II.

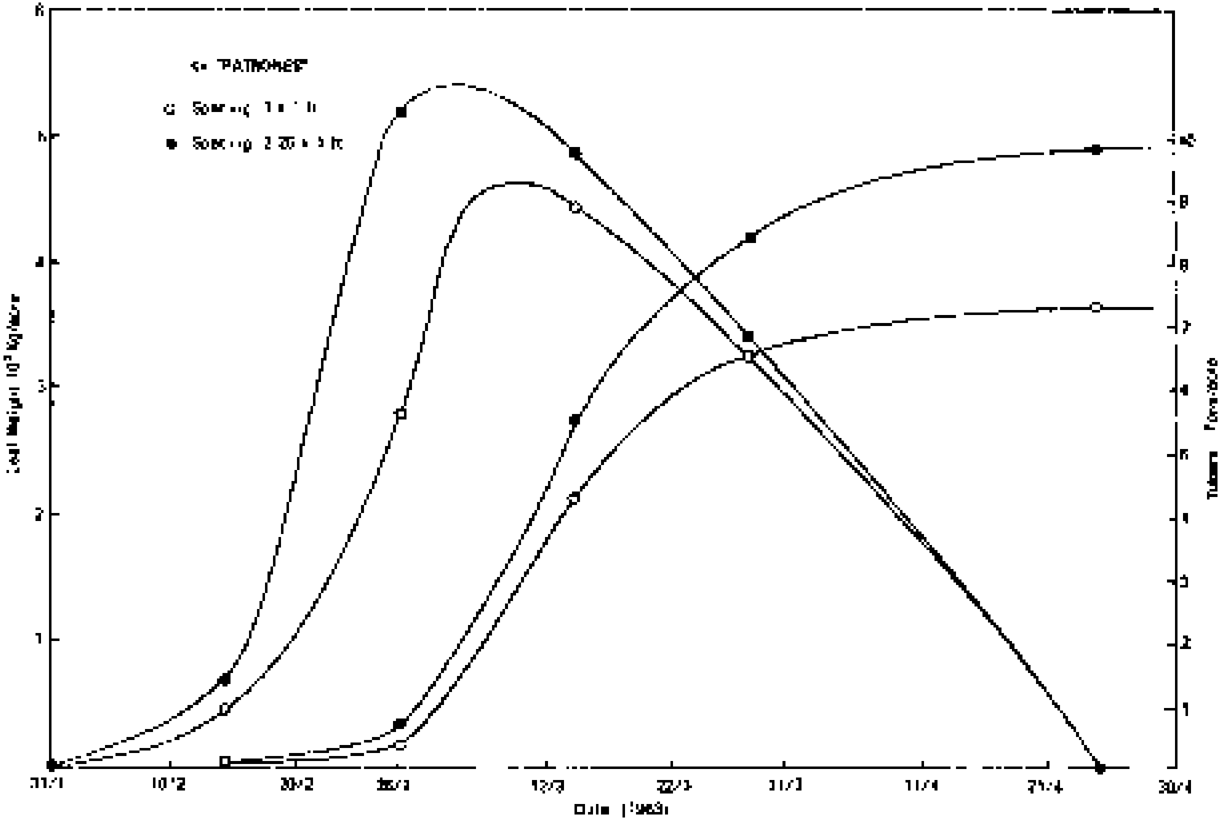

Fig 1 TUBER BULKING AND LEAF WEIGHT DEVELOPMENT

Table II NAR's (E_w) g/g/week

Period	14.2/28.2		28.2/14.3		14.3/28.3	
Spacing	3x1 ft	2x1 ft	3x1 ft	2x1 ft	3x1 ft	2x1 ft
Cultivar						
Patrones	1.80	1.89	1.44	0.98	0.53	0.61
Alpha	1.84	2.18	1.46	1.06	0.89	0.91
Eigenheimer	1.74	2.21	1.26	0.75	0.68	0.69
Mean	1.79	2.09	1.39	0.93	0.70	0.73
Coefficient of variation %	32.2		30.9		66.9	

The data presented in Table II show that there was an overall decline in E_w throughout the six week period. This was not altogether unexpected because during the period leaf weight was increasing rapidly and this must have led to increased shading of the lower leaves of the crop. The only significant differences found were during the period of 28.2/14.3 63 when the spacings showed significant effects (P—0.01). However it is clear from the final yields that the extra leaf area per unit plot area was more than enough to compensate for this and so highest yields resulted from the plots with the closer spacing.

During the same season a small plot experiment was laid down to obtain data on the fertiliser requirement of the crop. Small plots were used because seed tubers were in short supply and maximum information had to be obtained with the material available.

The plot size used was 36 sq. ft and the trial was a 3 factorial with 2 replications having the following treatments:

N at 0, 200 or 400 lb/acre as calcium ammonium nitrate
P_2O_5 at 0, 200 or 400 lb/acre as super-phosphate (45% P_2O_5)

K_2O at 0, 150 or 300 lb/acre as muriate of potash

Due to the shortage of seed tubers "Eigenheimer" was utilised for one replicate and "Patrones" for the other and guard rows were planted with "Alpha". The method of planting, fertiliser application and irrigation was exactly the same as for the first trial.

The yields in tons per acre are shown in Table III.

Table III. Yields in tons/acre—fertiliser trial

		P_2O_5 lbs per acre			K_2O lbs per acre			Mean
		0	200	400	0	150	300	
			+0.367 (3)					+0.213 (1)
N	0	6.923	2.617	8.904	7.346	8.454	7.644	7.815
lbs/acre	200	6.347	7.797	8.130	6.977	7.112	8.184	7.425
	400	5.339	6.968	7.572	6.095	7.031	6.752	6.626
P_2O_5	0				6.113	6.446	6.050	6.203
					6.716	7.364	8.301	7.463
lbs/acre	200				7.590	8.787	8.229	8.202
lbs/acre	400					+0.213 (2)		
Mean					6.806	7.532	7.527	7.289

There was a very marked response to phosphate even at the highest rate of 400 lb P_2O_5 per acre and the magnitude of this response was not in keeping with results of numerous fertiliser trials on other crops carried out on the University Farm over a period of years. For example Chapman (1957) found a good response to nitrogen on maize but little effect from phosphate or potash. However it is possible other factors were operative in that particular trial as it was carried out during the wet season as were most of the general fertiliser trials. It is possible that only when soil conditions are optimum the best response from fertilisers can be expected. However a more likely explanation is that the potato, being a very short term crop with little development of root, would be expected to respond markedly to fertiliser application. A longer term crop with a stronger root development would be better able to obtain its requirements from a limited soil nutrient supply. The response to nitrogen was surprising and it is suggested that the dosage was supraoptimal.

EXPERIMENTAL (1964)

It was decided in the following year both to investigate the effect of lower rates of nitrogen on the yield of potatoes and to attempt to grow one acre of potatoes commercially.

In the nitrogen trial, three rates 0, 75 or 150 lb/acre were used with calcium ammonium nitrate as the N source. An overall dressing was applied to all plots of 500 lb/acre P_2O_5 as super-phosphate and 180 lb/acre of K_2O as muriate of potash. New seed tubers "Patrones" were imported and planted at a spacing of 2.25 x 1ft. The plot size was 607 sq. ft and the three treatments were arranged in a randomised block design with five replicates. Irrigation procedure followed that of the previous year.

Two samples each of five plants, were removed from each plot at intervals of fourteen days for the determination of leaf areas and net assimilation rates. The availability of a leaf area photometer enables E's to be expressed in terms of leaf area (E^A). As in the previous year, the samples were divided into leaf, stem, root and tuber and sub samples were taken for the determination of dry matter. A sub sample of the leaves from each main sample was taken for the determination of leaf area.

Results

The yield of tubers expressed in tons/acre are given in Table 4.

Table 4. Yields tons/acre

Treatment N lb/acre	Yield tons/acre
Control	7.936
75	10.232
150	11.782
Mean	9.983
SE +	1.413
Coefficient of variation %	14.1

The yield of tubers and leaf area indices (L) at each of the sampling times are given — Table 5 and E for three 14 days periods are presented in Table 6.

Table V Yields of tubers in tons/acre and leaf area indices at each sampling

	Sampling date									
	13.2.64		25.2.64		10.3.64		24.3.64		7.4.64	
Treatment	Yield	LAI	Yield	LAI	Yield	LAI	Yield	LAI	Yield	LAI
Control	—	0.734	0.982	2.795	3.675	2.817	8.163	1.805	8.221	0.512
75 lb/acre, N	—	0.831	0.977	3.753	5.725	4.284	8.348	2.401	10.524	1.240
150 lb/acre, N	—	0.710	0.778	3.569	4.640	5.394	8.346	2.623	13.275	1.312
Mean	—	0.758	0.913	3.372	4.680	4.165	8.286	2.276	10.673	1.023

Table VI Net assimilation rates for the period shown as affected by treatments, g/m² per week

	Period		
Treatment	13.2 to 25.2.64	25.2 to 10.3.64	10.3 to 24.3.64
Control	0.49	0.40	0.55
75 lb/acre, N	0.53	0.35	0.17
150 lb/acre, N	0.46	0.36	0.12
Mean	0.49	0.37	0.28
SE+	0.06	0.08	0.11

It can be seen that nitrogen gave a positive result and increased yields thus confirming that the rates used in the previous year were excessive.

A comparison between yields of tubers obtained from the sampling on 7.4.64 (Table 5) and final yields (Table 4) reveals a discrepancy. However this is explicable in that irrigation was carried on too long and considerable rotting of tubers occurred before the final harvest. Jackson (1962) pointed out the damaging effects of excessive soil moisture to potatoes particularly at high soil temperatures. The effect was exacerbated in this trial because even at harvest the skins of the potatoes had not "set" and even limited storage after harvesting was a problem.

The data in Table 5 indicate that although nitrogen increased leaf area indices considerably, it was not until well after L had reached a maximum that substantial differences in tuber weights were found between treatments. Thus it appears that the increase in peak L due to nitrogen did not improve the efficiency of the plants but merely produced excessive foliage. The main beneficial result of nitrogen application was in maintaining leaf area prior to harvest. Indeed at the time of harvest the foliage on the control plots was dead but that of the plants treated with nitrogen was green. The haulms on treated plots were sprayed with Gramoxone prior to harvest. This was a mistake and the potatoes on these plots should have been allowed to mature naturally. It can be seen also from Table 6 that EA on control plots was maintained throughout the period under test but that it fell considerably on nitrogen treated plots as the crop grew.

DISCUSSION

Reasonable yields of potatoes can be obtained under the conditions experienced in Trinidad during the dry season provided irrigation is employed. To obtain good yields a suitable cultivar must be grown, at a specific plant spacing and using a fertiliser dressing of an approximately 6.20.6 composition. It is possible that a basal fertiliser dressing of phosphate and potash might be more benefical, followed by a side dressing of nitrogen at the time of peak L. The side dressing would be difficult to apply in practice however and a better alternative might be to give a small dressing at planting followed by foliar applications of urea after peak L. In this way the excessive production of foliage might be avoided and the maintenance of leaf area after peak L might be achieved.

The values for EA and EW are in themselves largely irrelevant. The rather tedious procedure of determination was used to explain some of the factors underlying the final yields. In this case the values did help explain some of the results and were comparable to those quoted by Thorne (1960).

Large scale trial 1964

Following the promising results obtained by Gooding and the indications found from work in 1963 it was decided to grow potatoes in a larger area and under commercial conditions. The final test had to be a large scale one.

An area of approximately one acre was cultivated and ridged by tractor. 300 lb. of calcium ammonium nitrate, 1100 lbs. of super-phosphate and 300 lbs. of muriate of potash per acre were applied in the furrows. A cultivation tine was drawn along each furrow to mix the fertiliser into the soil and prevent possible scorching of shoots after the tubers had sprouted. The furrows were 2.25 ft. apart. Seed tubers cv. "Patrones" were planted approximately 1 ft. apart in the furrows. Hand labour was used to cover the tubers because efficient mechanical means were not available.

Two interrow cultivations and a final moulding were carried out before the haulm growth covered the rows completely. Irrigation, amounting to one acre inch per week, was applied at 7 day intervals.

Some disease occurred but it was not serious. The disease was identified as *Alternaria solani* and periodic spraying of "Perenox" were carried out. However pests were a serious problem the main one being a species of Prodenia. It was difficult to obtain a good spray coverage and control was never really effective.

Yields were low and a total of 4.8 tons/acre only was achieved. This low yield was partly the result of losses due to rotting of tubers in the ground before harvest. It was not possible to estimate the amount lost by rotting. Chapman and Squire (1964) analysed the cost of production and showed that this particular crop realised a loss of $WI 532.60 per acre. This was the result of several factors, such as high costs of labour due to low productivity and inexperience, excessive irrigation costs etc. but even if these were corrected a loss of $WI 161.80 would have been realised.

To be profitable, yields would have to be raised to 7 or 8 tons/acre but this will be difficult under commercial conditions in Trinidad.

CONCLUSION

Good yields of potatoes can be obtained in small plot experiments in Trinidad but on a larger and more commercial scale, yields were lower and a loss was made. It is possible that on a more amenable soil with better irrigation control, economic yields might be obtained

SUMMARY

A series of small plot trials with *Solanum tuberosum* was carried out in the dry season of 1963 and 1964 in Trinidad. These culminated in an attempt to grow a large area under commercial conditions in 1964.

As a result of these trials it was possible to confirm Gooding's (1961, 1964) findings concerning the possibility of producing good yields experimentally with some varieties under Trinidad conditions. It was also possible to gain some information concerning an optimum fertiliser regime and this was in the region of 2,000 lb/acre of a 6.20.6 mixture.

However the large scale trial failed to give economic yields.

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APPENDIX 1

Week	1963		1964	
	Max.	Min.	Max.	Min.
1	86.6	69.8	83.0	67.3
2	86.4	65.9	83.3	64.7
3	87.4	65.9	82.9	63.4
4	87.3	66.4	83.0	65.0
5	88.1	67.1	86.0	65.0
6	87.7	68.4	86.4	68.0
7	87.1	68.0	85.7	——
8	86.4	67.4	86.3	71.4
9	88.6	67.1	85.0	68.4
10	87.7	65.4	86.3	67.7
11	88.8	67.3	87.9	68.3
12	89.7	65.3	87.7	67.9
13	89.7	67.4	88.9	68.7
14	86.9	69.7	85.3	69.6
15	86.3	67.7	84.9	70.9

Week 1: Week beginning 21.1.63 and 4.1.64.

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CASSAVA IN THE MALAGASY REPUBLIC

Research and Results

— *by* —

M. Arraudeau

Cassava was first introduced in the Western part of the Indian Ocean by the Frenchman Mahe de la Bourdonnais who imported it in 1739 to Mauritius and Reunion. It is noted that several deaths occurred due to the high HCN content of the first introductions. Introduction to Madagascar occurred in 1790 and the crop gradually spread throughout the island. The present area under cultivation is about 300,000 hectares yielding a total of 900,000 tons, i.e. an average yield of about 3 tons per hectare.

I. *Production Methods*

There are two methods of production:—

(a) *Extensive* production practised by the small farmers throughout the island.

(b) *Intensive* production, which is usually practiced by large companies owning vast acreages of land under cassava around a factory producing cassava flour and tapioca.

(a) Extensive Production

Cassava recurs infrequently at high elevation where the temperature is low but is grown universally at low elevations, particularly close to the villages. In this system it occupies small areas and is frequently intercropped with maize, beans and other crops. Under these conditions the culture of cassava is more or less neglected. The crop serves as a "ground reserve of food" which peasants harvest as and when required. Such condition do not enable objective estimates of yield and area under cultivations to be made. This must be bourne in mind when considering the data presented above. While yields are low, certain plants may produce very large roots.

In this method of cultivation, there are no standard practices as regards planting density, method of planting, date of planting and harvesting and even less as regards fertilizer application and crop rotation. It represents nevertheless, three quarters of the area under cassava in the Malagasy Republic.

(b) Intensive Production

Farmers growing cassava alone are not common in Madagascar but several of them, especially near to the processing plants, grow cassava as their main crop.

(a) *Crop rotation and green manuring*

The practice varies but the most common method is the growing of a green manure crop before planting the cassava (green measures are either maize or a legume like Crotolaria, Tephrosia or Vigna). Other crops in the rotation may also include groundnuts and paddy rice.

(b) *Land Preparation*

The green manure is turned in with 20-30 tons/ha of farmyard manure, the field is ploughed to a depth of 20-25 cm followed by disk harrowing, sometimes followed by banking in the humid areas. Organic manuring is often complemented by fertilizer applications of 500kg/ha of rock phosphate and of 300 kg/ha of muriate of potash; nitrogen is not added since it is contained in the green manure and it is advisable to avoid an excess of nitrogen on this crop.

(c) *Planting*

Cuttings 25 cm long with 8-15 nodes are planted either horizontal or slightly inclined. The planting distance is 80 x 80 cm. (15,600 plants per hectare) and in poor soils and 1 x 1 m (10,000 plants per hectare). The planting season is either March, i.e., at the end of the rainy season or in August-September which is more risky due to drought conditions.

(d) *Maintenance Operations*

These consist in supplying one month after planting and weeding when the cuttings start sprouting.

(e) *Harvesting*

This is done mechanically by means of heavy tractors on a large scale or by hand on smaller farms. In the latter method harvesting is more thorough as fewer roots remain in the soil. Yields reach 25-30 tons/ha and may go as high as 50 tons/ha under the best conditions. The crop cycle varies from 10 months on the coast to 24 months on the high plateaux.

II. *Losses due to pests and other factors*

Losses are caused by hail, aseptic rotting and root lignification. These vary considerably in importance according to the regions and to the years.

The main pests consist of 2 large groups of diseases: rots caused by fungi (*Gloeosporium manihotis, Phaeolus manihotis, Clitocybe tabescens, Armillariella* sp and *Diplodia* sp.) or by bacteria; and mosaic virus which is transmitted by *Bemisia manihotis*.

The selection of cassava cultivars in the Malagasy Republic is based on resistance to these two groups of disease.

III. *Research and Results*

The "Institut de Recherches Agronomiques a Madagascar" (IRAM) has for several years undertaken research with the objective of improving the cassava cultivation. Studies have been initiated on both cultural techniques and improvement of varieties.

1. Cultural Techniques

From what has been said above, it may be considered that sound techniques of cultivation are now firmly established, especially after several years of field studies, in particular on nutrient needs according to soil type.

It is a known fact that, based on a yield of 40 tons of roots and 50 tons of stems, one hectare removes approximately 285 kg N, 132 kg P_2O_5, 460 kg K_2O and 225 kg CaO. From these figures a rational fertilizer guide may be arrived at, bearing in mind the fact that nutrients are made up of an organic part (green manure and pen manure and an inorganic part (mineral fertilizer).

Chemical weed control is about the only cultural technique still under study in Madagascar and it is too early to draw conclusions.

2. Plant Breeding

Improvement of varieties is being attempted at the "Station Agronomique de Lac Alaotra" where a collection of 334 clones is maintained. Part of these (170) are hybrids bred at the Station itself (both intergeneric crosses and interspecific crosses with *M. esculenta*, *M. glaziovii* and *M. pringlei*). This collection is thus an important stock of vegetative material for further crosses.

(a) *Objectives*

There are 3 main objectives: high yields, resistance to mosaic viruses and resistance to root rots, with secondary objectives of: plant habit for uniform branching, quick ground cover with a bushy form, high starch content and quality of the starch, thin root bark, white phelloderm, good shape and distribution of roots and drought resistance for growing in the dry southern areas.

(b) *Breeding of new clones*

This is carried out by several hybridisation techniques —

(i) by single crossing, i.e., crossing of 2 clones. Since clones are heterozygous, it is impossible to predict the results but the probability of obtaining better results from the crossing of two superior clones is made use of. Thus it is likely that crossing one clone resistant to mosaic with one resistant to rots will produce a hybrid resistant to both diseases. In fact we have observed experimentally that certain clones are always better parents than others in all crossings although these same clones are not necessarily the best in comparative trials;

(ii) by crossing a male sterile clone with promising male fertile clones;

(iii) by polyclonal crosses;

(iv) by random harvesting of seeds from the plant collection.

The results obtained have shown that the chances of obtaining a superior hybrid are equal in the first 3 methods (out of 5,000 seeds obtained, at the most only one superior hybrid is finally selected).

(c) *Selection of clones*

Seeds are sown in a sandy soil to obtain good germination and each individual is examined from the second year for the above-mentioned characteristics. In this first stage about 80% of the clones are rejected. Six cuttings from each selected plant are replanted and again examined after 2 years of growth. In this second stage about 60% of the clones are eliminated; the remaining plants are then used in 3 selection cycles on plots that gradually increase in size, up to 1-1½ after six years. This results in a selection of 2 or 3 clones for every thousand clones at the start. At the end of these 10-year selections, the selected clones are compared with local cultivars in yield trials. At the "Lac Alaotra" Agronomic Station, a total of 57,000 seedlings have been selected over a period of 25 years, i.e., an average of 2,500 clones per year from 4,000-6,000 seeds obtained from breeding.

(d) *Results*

IRAM has by now made available several very promising clones to cassava farmers. Certain clones are particularly suitable for specific conditions but others can be grown under a wide range of conditions. The list of clones available with their main characteristics is given below.

Hybrid 34 : very bitter, mosaic resistant, susceptible to rot, high starch content; adapted to high elevation and well-drained soils.

Hybrid 35 : quite sweet, moderately resistant to mosaic, quite resistant to rot; suitable for fertile soils and wet areas.

Hybrid 41 : quite sweet, quite resistant to mosaic, little resistance to rot; for well-drained and fertile soils.

Hybrid 43 : sweet, mosaic resistant, little resistance to rot; rapid growth, high yielding in dry areas.

Hybrid 45–47 and 52 : very sweet, quite resistant to mosaic and rot; for fertile and well-drained alluvial soils. The sweetest clones in the collection.

Hybrid 49 : bitter, quite resistant to mosaic and rot, good sprouting characteristics; suited to dry hillsides and plateaux but susceptible to low temperatures.

Hybrid 53 : sweet, quite resistant to mosaic and rot; for fertile areas and fairly dry areas and hillsides.

Hybrid 54 : quite sweet, mosaic resistant but less so to rot; high yielding or alluvial soils and excellent response to fertilizer.

Hybrid 55 : bitter, resistant to mosaic and highly resistant to rot; suitable for low elevations and high moisture.

Hybrid 56 : quite sweet, highly resistant to mosaic and rot; excellent yields and responds very well to fertilizer; good uniform growth habit.

Hybrid 57 : quite sweet, highly resistant to mosaic and rot; high yields and responds very well to fertilizer; for low elevations and humid conditions.

In comparative yield trials, yields obtained have been as follows:—

Dry and low lying areas	:	Local varieties – 7-8 tons/ha hybrids – 12-35 tons/ha (H. 43, H. 53, H. 54)
Humid and low lying areas	:	Local strains – 9-25 tons/ha. Hybrids – 28-66 tons/ha. (H. 45, H. 53, H. 54, H. 56 and H. 57).
Areas of medium altitude	:	(300-900 metres). Local strains – 4-20 tons/ha. Hybrids 30-80 tons/ha. (H. 35, H. 49, H. 54, H. 57).
Areas of high altitude	:	(900-1300 metres). Local strains 4-12 tons/ha. Hybrids – 12-25 tons/ha. (H. 54, H. 56 and H. 57).

Conclusions

Results obtained in the Malagasy Republic with hybrids used commercially point the way to a marked improvement in production of the crop. Although it may be difficult on a larger scale to duplicate the high yields obtained in trials, it is certain that, with the high level of management described, average yields of 30 tons/ha are possible and have in fact been obtained. The hybrids available actually constitute only one stage of the continuing breeding programme whose essential aim is the development of cultivars completely resistant to mosaic and rot, with high yields and for either direct consumption (fresh or dried) or processing, i.e., with a high starch content.