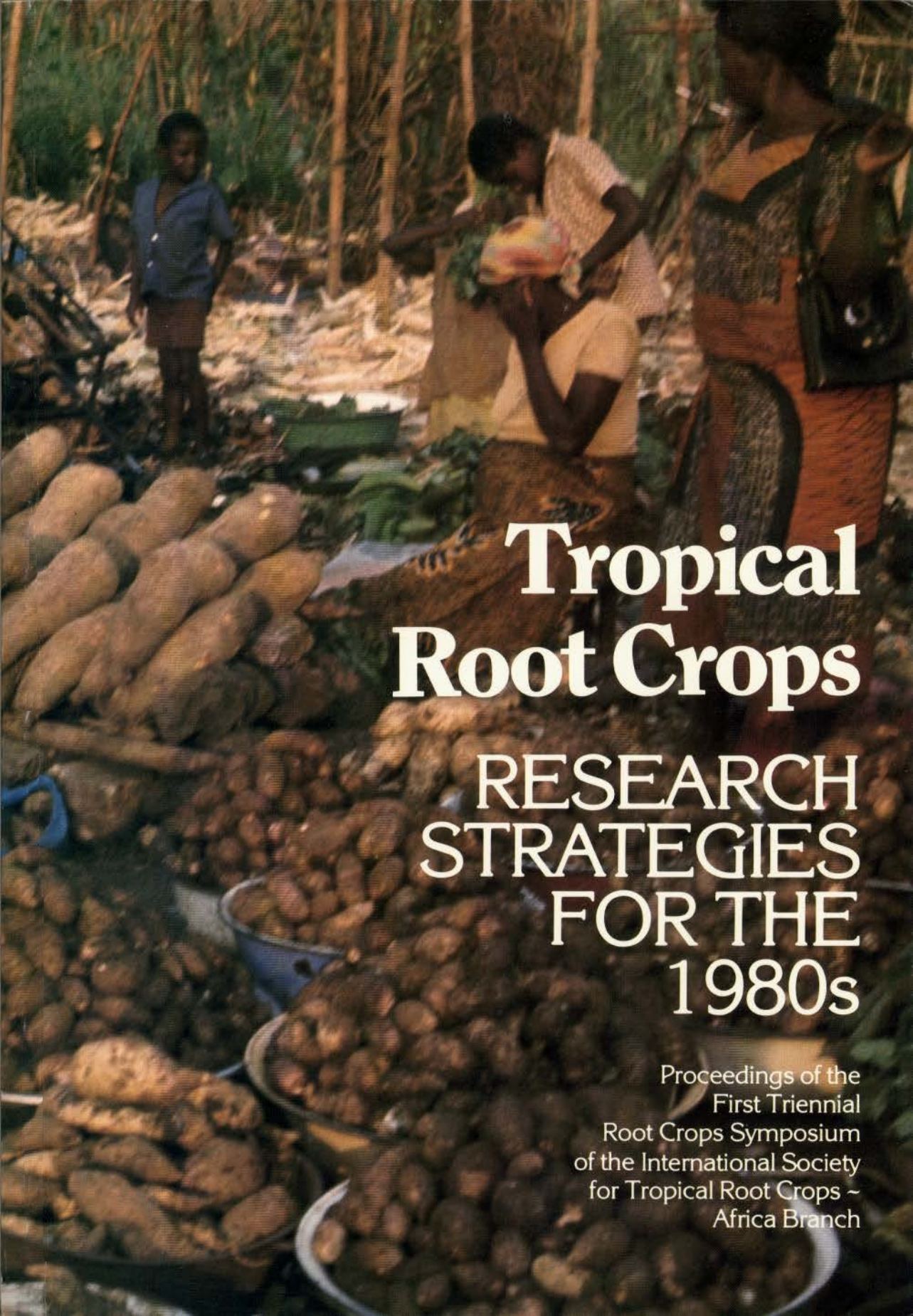

Tropical Root Crops

RESEARCH STRATEGIES FOR THE 1980s

Proceedings of the
First Triennial
Root Crops Symposium
of the International Society
for Tropical Root Crops ~
Africa Branch

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TROPICAL ROOT CROPS: RESEARCH STRATEGIES FOR THE 1980S

PROCEEDINGS OF THE FIRST TRIENNIAL ROOT CROPS SYMPOSIUM OF THE INTERNATIONAL SOCIETY FOR TROPICAL ROOT CROPS — AFRICA BRANCH, 8–12 SEPTEMBER 1980, IBADAN, NIGERIA

EDITORS: E.R. TERRY, K.A. ODURO, AND F. CAVENESS

Although the editorial chores for these proceedings were the sole responsibility of the editors, the International Society for Tropical Root Crops — Africa Branch has a full Editorial Board comprising E.R. Terry, O.B. Arene, E.V. Doku, K.A. Oduro, W.N. Ezeilo, J. Mabanza, and F. Nweke. This Board serves the Society in various editorial capacities at all times.

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The International Society for Tropical Root Crops — Africa Branch was created in 1978 to stimulate research, production, and utilization of root and tuber crops in Africa and the adjacent islands. The activities include encouragement of training and extension, organization of workshops and symposia, exchange of genetic materials, and facilitation of contacts between personnel working with root and tuber crops. The Society's headquarters is at the International Institute of Tropical Agriculture in Ibadan, Nigeria, but its executive council comprises eminent root and tuber researchers from national programs throughout the continent.

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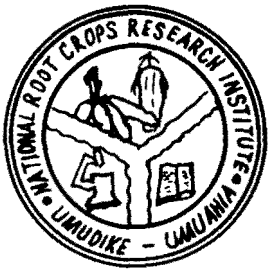

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FOREWORD

The International Society for Tropical Root Crops — Africa Branch (ISTRC — AB) held its first symposium at the International Institute of Tropical Agriculture (IITA) in Ibadan, Nigeria, 8–12 September 1980.

The symposium, which had as its theme strategies for progress in root crops research in Africa, attracted nearly 100 participants from 14 African countries. It was a unique opportunity for exchange among agronomists, breeders, plant pathologists, economists, and entomologists, exemplifying the role the Society can play as an effective instrument in strengthening communication among root crops researchers. The quality of the research upon which the presentations were based is demonstrated in these proceedings. The symposium was addressed by the Nigerian Minister of Agriculture, the Honourable Alhaji Ibrahim Gusau, who pledged the support of the federal government of Nigeria toward the achievement of the Society's aims and aspirations.

The 48 scientific papers presented during this 5-day symposium focused on the four major root crops of the humid tropics — cassava, yams, sweet potatoes, and cocoyams. Theme papers for cassava, yams, and cocoyams outlined research strategies for the 1980s; together with the other presentations, they generated the discussions from which emerged specific recommendations. It is hoped that international funding agencies, national governments, research institutes, and development organizations will provide the needed financial and personnel support to translate these recommendations into action.

Addressing a particular concern of root crops researchers, a five-person panel of symposium participants discussed the topic: Is the yam threatened with extinction? At present, production constraints and costs are a major deterrent to yam cultivation, but the cultural and nutritional value of the crop ensures a continued demand. Thus, the consensus at the meeting was that research should be directed toward the search for cultivars with characters that minimize the production constraints.

The executive council and all the members of the ISTRC–AB hereby express their sincere gratitude to the following donors, whose financial contributions facilitated the organization of the symposium and the publication of these proceedings: the International Development Research Centre (IDRC), International Institute of Tropical Agriculture (IITA), Ford Foundation, International Foundation

for Sciences (IFS), the parent body of the ISTRC, the federal government of Nigeria, the International Fund for Agricultural Development (IFAD), the United Nations Development Programme (UNDP), and the National Root Crops Research Institute (NRCRI) of Nigeria.

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As President of the International Society for Tropical Root Crops — Africa Branch, I take this opportunity to remind you that it is now 10 years since the parent body (ISTRC) was founded as a followup to ideas and aspirations that cropped up during the First International Root Crops Symposium in St. Augustine, Trinidad, 2–8 April 1967. During the Fourth Symposium of ISTRC at CIAT, Colombia, in 1976, the ISTRC — AB was conceived, and after a gestation of more than 2 years and several months of labour, the Africa Branch was born on 30 June 1978 with Dr Sang Ki Hahn in attendance. I, therefore, regard this First Triennial Symposium as a memorable occasion; to me it constitutes more or less the coming-out ceremony of the ISTRC — AB. It is an auspicious occasion on which to remind the distinguished gathering today that the main objective of the Africa Branch of the ISTRC is the fostering of all activities that enhance progress in studies, publications, communication, and knowledge of tropical root and tuber crops so that the full potentials of these crops can be realized through their increased production, processing, distribution, and utilization. Also through symposia, conferences, and various meetings, it is hoped that there will be increased contact and exchange of ideas, materials, and information among workers on root and tuber crops on the African continent. Root crops, generally speaking, are those crops purposely cultivated or otherwise exploited for their carbohydrate-rich underground, and rarely for their aerial, storage organs in the form of swollen roots (cassava), modified stem structures (tubers in yams, corms in cocoyams, and rhizomes in ginger). It is the preoccupation of members of this Society to promote the growth and utilization of major and minor indigenous or exotic root and tuber crops grown in Africa and adjacent islands. Of major importance to the Society are the white, yellow, and water yams; cassava; sweet potato; cocoyams; and Irish potato, which is important at high elevations in the tropics. Of minor importance are some of the yams (*Dioscorea bulbifera, D. dumetorum*, etc.), ginger (*Zingiber officinale*), tigernut (*Cyperus esculentus*), kaufir potato (*Plectranthus esculentus*), Hausa potato (*Solenostemon rotundifolius*), carrot (*Daucus carota*), turmeric (*Curcuma longa*), garden beets (*Beta vulgaris*), radish (*Raphanus* spp.), Jerusalem artichoke (*Helianthus tuberosus*), and African yam bean (*Sphenostylis stenocarpa*). A few species of roots and tubers including some species of *Amorphophallus*, *Tacca*, and *Achomanes* are sometimes harvested from the wild.

International agricultural research centres such as the International Institute of Tropical Agriculture (IITA) are giving priority only to the major root and tuber crops. Many of the others such as risga, Hausa potato, and African yam bean, which are indigenous, are receiving little attention; yet in some localities these crops are of relatively high status or may be more nutritionally strategic than expected on the basis of production figures.

It is necessary at this stage to consider why there is need for a strong and active branch of the ISTRC in Africa. In 1977 Africa accounted for about 22% of the world's area of land under root crops, but production of root crops and average yield figures amounted to 14 and 62%, respectively, of the corresponding world figures. More than 90% of the world's land area under yams and more than 90% of the world's tropical root crops production each year occur in Africa. Similarly, up to 53% of the land area and 42% of the world production of cassava are in Africa. The low yields of root crops in Africa emphasize the need for greater efforts in research, extension, and training. Root crops in the humid and subhumid zones of Africa are greatly relied upon as major subsistence staples. The importance of root crops as major staples is related to their ability to grow on different soils whenever rainfall is adequate, the relatively little care they require in terms of labour and other inputs used in their production, the relative ease with which they can be stored without processing or drying in a highly humid environment as compared with cere-

als, the relatively fewer serious pests and diseases in root and tuber crops compared with cereals and legumes, the convenience with which some root crops such as cassava can be left in the ground as food reserves until required, and their general adaptability to humid environments and peasant-farmer production systems. Although these obviously are factors that have endeared root crops to small farmers in the humid tropics, the continued production and increased utilization of root and tuber crops will depend on the extent to which solutions are found for problems such as their high moisture content (60–84%), which renders them bulky to handle in trade, marketing, and storage; their awkward shapes and large size, which predispose them to bruising in transit and secondary infection by microorganisms; their labour requirements, which are higher per hectare than are those for cereals despite the high yield and relatively low labour requirement per unit weight or per calorie produced of root crops; their intractability to mechanization; their reluctance to propagate by seed (vegetative propagation in which a considerable portion of the edible part of the crop, except in cassava, is used up during planting is widespread); and the obvious marketing and storage problems in root and tuber crops, most of which are handled with little processing. Thus, as indicated already, interest in root and tuber crops has always lagged behind industrial cash crops, cereals, and legumes. The so-called green revolution is limited to a few cereals (maize, rice, and wheat). Moreover, the relatively lower nutritional value of root and tuber crops and the greater availability of technology for production, storage, and processing of cereals into convenience forms as compared with root and tuber crops have resulted in much lower priority being given to root and tuber crops by developed countries in funding research, technical assistance, and development projects. I hope that during this symposium there will be frank exchange of ideas on the advantages, disadvantages, biases, and potentials of root crops in efforts to offset the increasing food deficit in countries of tropical Africa. I also hope that the outcome of this continuing debate on research and development of root and tuber crops will be a more balanced view and integrated approach toward improvement, production, storage, processing, and marketing of tropical root crops and their products. There is no doubt, however, that if half as much of the resources devoted to research, production, and utilization of cereals and grain legumes were allocated to root crops, a second green revolution could be achieved in root and tuber crops. This would make them available in as wide a range of convenience forms as possible and would minimize the reliance on grain imports to satisfy Africa's food requirements.

In ending my remarks, I find it necessary to point out that with some of the prevailing biases against root crops despite their importance and relatively untapped potentials, the participants at this symposium should consider various ways of setting ISTRC — AB on a firm financial footing. The prolonged period between the founding of the Africa Branch of ISTRC and this first symposium is mainly due to the Society's poor financial position. Yet one cannot overemphasize the urgency in the need for increased production of root and tuber crops to satisfy the likely increased demands for these crops as food for humans, feed for livestock, and more recently industrial uses of cassava for alcohol. Surplus production is required to ensure that the nutritional welfare of Africa's people is maintained at a reasonable level.

On behalf of the ISTRC — AB, I thank all those whose donations and activities have made this symposium possible and especially all distinguished guests who have honoured our invitations as well as all participants who are presenting papers or have accepted responsibilities in different symposium activities. I look forward to interesting and fruitful deliberations and exchanges of information and ideas.

ALHAJI IBRAHIM GUSAU

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I welcome you all to this symposium on behalf of myself and the government and people of this country. I wish to welcome to Nigeria especially those foreigners in our midsts. I wish them a very pleasant and rewarding visit.

You are holding this symposium, which I understand is the first of its kind in Africa, at a momentous time in the history of this nation, a time when this country is preparing for a determined war against hunger and malnutrition, enemy number one. This administration has proclaimed a green revolution as its priority. The government is resolved to be self-sufficient in all the basic food items in the quickest possible time. It has consequently drawn up a program of action, most of which will be executed during the Fourth National Development Plan, which begins in January 1981.

In the Nigerian context, self-sufficiency means much more than being able to stop the importation of staples such as rice, maize, and wheat; it means also having enough to spare for the less-fortunate countries, especially those who experience perennial adverse weather conditions and acute food shortages. We Nigerians cannot ignore what happens across our borders because the African economies are inextricably woven together.

The root crops economy is, as is well known, extremely important to the continent of Africa. I am informed that yams, cassava, sweet potato, and cocoyams together supply 25–30% of the total energy intake and about 13% of the protein intake in the West African subregion. Cassava and yams, which are the most important root crops in Nigeria, can grow well virtually throughout this country, and they are eaten in almost all households. It is therefore imperative that scientists, extension workers, and producers in Africa come together and exchange experience and information so that they can bring about rapid improvements in the production of these important crops.

Another reason that your meeting is of great relevance now is that cassava is facing a serious threat of extinction in the region. I am referring to the combined threat of the cassava mealybug and the red spider mite that is now ravaging the crop in the central and west African subregions. My ministry is taking bold steps to combat these two pests in collaboration with IITA and Texagric, a subsidiary of the well-known oil company, Texaco. Because these two pests can easily be transmitted across international borders, the cooperation of plant quarantine officers in the region is vital. In other words, although the exchange of planting material is very important in the improvement of any crop, the time has come when extreme caution has to be exercised particularly with respect to cassava. A few years back the bacterial blight of cassava came to this country with planting materials, and it took a great deal of effort to rehabilitate the crop. Again, just as the producers were beginning to record bumper harvests, two pests replaced the earlier one. The eradication of these pests calls for the development of a collaborative program under the auspices of international agencies like the IITA and FAO and national research and extension organizations. I hope this meeting will afford scientists, extension workers, farmers, and consumers an opportunity to evolve new strategies for the control of these pests in particular and the production and processing of root crops in general.

Another crop to which I urge your Society to give more attention is yam. Despite the importance of this crop in the diet of millions of people in Nigeria and other parts of the African continent, new production technologies have been slow in coming. Many farmers are abandoning the crop because of its high labour demand. Ways of mechanizing the production of the crop must therefore be found. Potato is also becoming important in some parts of Africa, and research work should look ahead and develop high-yielding varieties.

I wish to observe at this juncture that progress has been slow in the development of the technology of storage and processing of the roots and tubers. You may therefore wish to consider this important

aspect of the root crop industry; better ways of storing and processing these crops would not only minimize losses but stimulate further production. In this connection, it is pertinent to point out that in recent times the federal government of Nigeria has invested heavily in integrated production and processing of root and tuber crops through the National Root Crops Production Company. This company now has a total of four estates in production and is producing large quantities of finished cassava products namely, gari, *fufu*, and cassavita, for sale throughout the country. The company and the federal department of agriculture have developed a plan to assist several cooperative societies and groups of farmers to establish processing facilities.

For these reasons, I hope you will give the proceedings of this symposium the widest possible circulation so that interested governments can take advantage of your expertise and experience. I wish you all a successful conference.

S. OLAJUWON OLAYIDE

VICE-CHANCELLOR, UNIVERSITY OF IBADAN, IBADAN, NIGERIA

The Nigerian food economy comprises cereals (maize, rice, sorghum, millet, wheat, and acha), pulses (cowpeas, peas, groundnuts, soybeans, lentils, etc.), roots and tubers (cassava, yams, potatoes, and cocoyams), and fruit trees that have starchy pulp (boabab, plantain, banana, African breadfruit, etc.), oilseeds, nuts, fruits, vegetables, sugars, and animal products (meat, fish, eggs, milk, cheese, etc.). About 50% of the world's yam crop is produced in Nigeria (Coursey 1967), and about 70% of the world's yam crop is produced in Africa (Coursey and Haynes). Cocoyam, sweet potatoes, Irish potatoes, and cassava are diffused across the continent from Asia and the Americas (Idusogie 1973). Macabo is another tuber that is much used in Cameroon and certain other African countries. It is a starchy root that is probably indigenous to Africa.

Food balance sheets indicate the grams of food, kilocalories of energy, and grams of protein derived from various food groups (Table 1). Starchy roots and tubers constitute about 15.79% of all calories and 10.02% of all proteins; they also form about 15.05% of total calories and 8.76% of total proteins in the daily diets of average Nigerians (Olayide et al. 1979). In other words, roots–tubers constitute a highly significant proportion of the national diet.

When these figures are examined on a geographical basis, it is evident that the southern states of Nigeria essentially house the root–tuber crop eaters whereas the northern states may be said to be predominantly inhabited by grain–cereal eaters (Idusogie and Olayide 1973).

An analysis of food demands and supplies in Nigeria with projections up to 1995 shows that root–tuber crops will continue to loom very large in the national diet (Table 2). Demands continue to outstrip supplies. In other words, there will be negative commodity balances running into thousands of tonnes for cassava, potatoes, yams, cocoyams, and plantains in Nigeria up to the turn of this century. For example by 1985, Nigeria will need either to produce or to import an extra 0.777 million tonnes of cassava, 0.035 million tonnes of potatoes, 1.623 million tonnes of yams, 0.078 million tonnes of cocoyams, and 0.109 million tonnes of plantains to augment domestic supplies. As a matter of fact, the demand may be even greater because of the rise in population.

The worsening food situation in Nigeria raises

Table 1. Nigeria: national food balance sheet 1975–85.

Food group	Consumption/ person-day (g)	Calories (kcals)	Protein (g)
Cereals	331.78	1132.805	35.085
Starchy roots and tubers	310.633	298.404	4.950
Pulses, nuts, and oilseeds	37.496	163.155	9.011
Fats and oil	31.517	237.904	–
Fruits and vegetables	37.462	2.410	0.469
Sugar	12.679	49.058	–
Meat	32.465	53.328	4.193
Fish	20.725	27.336	1.822
Eggs	6.808	6.386	0.748
Milk	9.747	6.336	0.339

Source: Olayide, S.O. et al. 1979. Food production in Nigeria (report of the Agricultural Statistics Working Party). Ibadan, University of Ibadan.

Table 2. Nigeria: projected demand and supply of root–tuber crops.

Root–tubers	Demand projections (Mt)			Supply projections (Mt)		
	1984–85	1989–90	1994–95	1984–85	1989–90	1994–95
Cassava	5.429	6.643	8.129	4.652	5.272	5.973
Potatoes	0.241	0.295	0.360	0.206	0.234	0.265
Yams	11.353	13.893	17.000	9.730	11.025	12.492
Cocoyams	0.545	0.667	0.816	0.467	0.529	0.600
Plantains	0.766	0.938	1.148	0.657	0.744	0.843

Source: Olayide, S.O. et al. 1979. Food production in Nigeria (report of the Agricultural Statistics Working Party). Ibadan, University of Ibadan.

serious issues of agrarian policy. These policy issues merit careful examination in the context of root–tuber crops production, distribution, planning, and research.

PRODUCTION

The production of roots and tubers in Nigeria is handled by millions of small-scale or smallholder farmers, 95% of whom farm fewer than 10 ha (Federal Office of Statistics 1976). These smallholder farmers produced 99.05% of the cassava, 99.99% of the yams, and 99.99% of the cocoyams harvested in Nigeria in 1974–75 (Federal Office of Statistics 1978). These producers face serious problems of low productive efficiency. Specifically, the small farmers have attained productive efficiencies of only 21.79% for cassava, 70.82% for potatoes, 19.53% for yams, 42.42% for cocoyams, and 50.05% for plantain when average yields are assessed in relation to potential yields (Federal Ministry of Agriculture 1974).

The farmers also face problems of inadequate production technology, inadequate capital (in terms of mechanical, physical, chemical, biologic, and monetary capital), excessive demands for labour, absolute dependence on rainfall, and complex land tenure systems. In addition, they operate diverse farming systems.

DISTRIBUTION

The distribution of root–tuber crops in Nigeria involves three functions. First is the transportation of the harvest from millions of farmers in the rural areas. Second is the equalization of products in terms of cleaning, sorting, grading, part processing, packaging, etc. Third is the merchandizing of the equalized products at local urban markets, and this function involves transportation, blending, regrading, and sale of raw or processed products.

The process of distribution involves millions of traders who operate under conditions of inadequate capital, considerable and inefficient bulk breaking, poor marketing facilities or infrastructure, poor market information systems, and inefficient "carrier" systems (Olayide 1969). The poor distribution system results in substantial crop losses that, for roots and tubers, range from 15 to 25% of harvests. The serious implications of these losses (amounting to several millions of naira) for the economy as well as the nutrition of Nigerians cannot be overemphasized (Idusogie et al. 1973).

PLANNING

Since the advent of national planning in Nigeria in the mid-1940s, considerable attention has been given to consistent programing designed to evolve self-sufficiency in the production and distribution of root–tuber crops. Planned budgets have been made for production of seedlings and stakes, fertilizer supplies, storage operations, large-scale plantations, and extension services among others. The plans have also taken into consideration the issues of the organization of production, special attention being given to cooperatives, partnerships, and corporate organizations.

In all the various planned programs, however, more than 95% of the budgets have been for public sector programs (Olayide 1976). In other words, what went to the actual producers of root–tuber crops was less than 5% of planned expenditures by government. The planning failed to emphasize effective and enforceable resource constraints; also the plans were subjected to considerable underspending and inefficient bureaucratization in implementation.

RESEARCH

Agrarian research, which dates back to 1893 when a botanic garden was established in Lagos by

Sir Claude McDonald, has given prominence to root–tuber crops research. Starting with the establishment of Moor Plantation in 1899, root crops research, which was undertaken by a department in the Federal Ministry of Agriculture but with field stations in many parts of the country, had sufficiently developed to warrant the establishment, by 1975, of a National Root Crops Research Institute (NRCRI) with headquarters at Umudike.

Root–tuber crops research has also been given considerable attention by university faculties of agriculture, state ministries of agriculture, and the IITA, but the research projects have essentially been of the basic experimental and applied experimental types. Little emphasis has been given to mission-oriented, remedial, adaptive, and extension research. The research result reporting systems involving conference papers, institute reports, journal articles, extension reports, and direct services have not been very effective (Olayide 1978). The resources committed to research, in terms of personnel, money, and materials, generally have been inadequate.

A general assessment of the state of knowledge in root–tuber crops research leads one to conclude tentatively that there will be the need to concentrate on the development of early maturing, disease-resistant, and high-yielding varieties that are easily and suitably adapted to the various ecological zones of the country. Studies will also need to concentrate on reducing the cyanide contents of cassava, improving the agronomic and cultural practices in yam and cocoyam cultivation, breeding easily harvested and fairly storable varieties of roots and tubers, determining optimal fertilizer levels, and evolving possibilities for the mechanization of production, harvesting, processing of root–tuber crops on small- and medium-scale farms. Studies will have to be geared to the needs and problems of the smallholder farmers (Olayide et al. 1979).

STRATEGIES

In the light of the policy issues involved in root–tuber crops production, distribution, programing, and research there is a need for broad strategies that accelerate the development of these crops to meet national demands. These strategies include:

- The reinforcement and funding of research geared to improving the production and distribution of root–tuber crops, with emphasis on high yields, disease resistance, fertilizer responsiveness, ecological adaptation, mechanization responsiveness, early maturation, storability, and enhanced nutrients;
- The provision of incentives to smallholder root–tuber crops farmers; possibilities are encouragement of cooperatives, supplies of inputs, and the provision of capital as well as new production technology;
- The elevation of root–tuber crops to the level of cash or market-oriented crops through improved storage, marketing, and contract-production programs backed by continuing research;
- The development of processing technology designed to reduce and eventually to eliminate the highly significant annual losses in harvested root–tuber crops; and
- The creation and active promotion of developmental, compensatory, organizational, regulatory, supportive, and remedial policy instruments for the implementation of root–tuber crops programs geared to meeting national demands.

These strategies rely essentially on carefully planned and executed research programs that are purposeful, rigorous, continuing, and cumulative. It is in this context that I consider this first symposium of the International Society for Tropical Root Crops — Africa Branch very appropriate, timely, and worthwhile. In these days of worsening farm, food, fibre, and nutrition problems, this Society has important roles to play especially with crops of international importance and significance. Unless the members of the Society rise to the occasion, the Malthusian spectre with rising deprivations will bedevil human socioeconomic welfare in the decades ahead.

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The African branch of the International Society for Tropical Root Crops — founded 3 years ago — has been an effective instrument in strengthening the communication among the scientists working on root crops.

During this week, participants have an opportunity to deal with the problems of major root–tuber crops of Africa and arrive at a strategy for collective effort on alleviation of the production problems. I have encouraged IITA staff to avail themselves of the opportunity to interact with participants and to keep this link in their future work. Since cassava was introduced into Africa by the Portuguese in the 16th century, it has been a historic boon for the African tropics and has been closely associated with the farming system of the humid tropics. Although some have accused cassava of impoverishing the soils, perhaps no other crop can grow in such poor soils. There is no crop failure for cassava; one has either a good or a poor crop, a point of strength for peasant agriculture. In the tropics, the only crops that grow through a dry season are cassava and pigeon pea. In this continent, cassava is afflicted by mosaic and bacterial blight diseases that have been the main focus of IITA's cassava-breeding program. The success that has ensued from this effort is one of the main reasons for the popularity of IITA in Africa.

Yams of various types are grown in the humid tropics all over the world, but the African yam is a prestigious component of diets. Several people have forecast the extinction of white yam in Africa because of the high cost of the product, demanding nature of the crop on the soil, labour intensity in its cultivation, etc. Despite these problems, yams still command a dominant position in African agriculture. IITA's research is focused on breeding white yam lines that are tolerant to virus and nematodes and that can yield well even when not staked. The techniques to cross and germinate seeds of white yam have opened a wide field of white yam breeding. Water yam (*Dioscorea alata*) is more tolerant to nematodes but is susceptible to "scorch" disease. IITA research has unraveled cultivars of water yam that are resistant to scorch disease.

Cocoyams have a shorter growing season than do yams and are adapted to hydromorphic and freely drained soils and to forest soils. They are easily cooked and cooked cocoyams are so easy to digest that they are infant foods. The recent discovery of how to induce flowering in cocoyams by spraying them with gibberellic acid has opened up a new field of research in breeding of this crop. With this new development, the seedling nurseries can be exposed to local disease and nematode stresses. A major problem that Cameroon and eastern Nigeria face now is the *Xanthosoma* blight. If researchers had not discovered how to make cocoyams flower, the only solution to blight would be that of changing from *Xanthosoma* to *Colocasia* (as was done in Cameroon) or to other species of *Xanthosoma*. Now, there is an alternative: to produce and introduce the true seeds and screen for resistance to the blight. The source of resistance can be incorporated through breeding into locally adapted cultivars.

Sweet potato — a preferred crop in Asia — is by far the most versatile root crop in its adaptation, being grown from temperate to tropical conditions. In a short period, it exceeds all other crops in productivity yet is tolerant to drought. This crop has an enormous future in Africa. Not too long ago in southeastern Thailand, hardly any cassava was grown; now this region is a major cassava producer and exporter. It is thus not unlikely that sweet potato will capture a wide patronage in Africa.

Crops that are normally vegetatively propagated but wherein seed production is possible offer a unique opportunity of opening up the genetic system and unfolding the genetic variation accumulated over the ages of vegetative propagation, and once a good genotype is formed, it can be propagated as a clone.

In an international effort of this nature, the African branch of the International Society for Tropical Root Crops can render a great service.

CASSAVA

CASSAVA IMPROVEMENT STRATEGIES FOR RESISTANCE TO MAJOR ECONOMIC DISEASES AND PESTS IN AFRICA

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The cassava diseases of major economic importance in Africa are cassava mosaic, bacterial blight, and anthracnose, and the major cassava pests are cassava mealybug and green spider mite. Methods of screening cassava breeding material for resistance to the diseases and pests in the light of factors determining the disease and pest incidence and their effect on efficiency of screening have been discussed. The role of the presence of pathogenic variation and biotypes of pests in determining the durability of resistance over localities and time has been considered, and the optimum conditions for efficient screening of the breeding materials have been suggested.

En Afrique, les maladies et ennemis du manioc d'une grande importance économique sont respectivement la brûlure bactérienne, l'anthracnose et la mosaïque dans le premier cas et la cochenille dans le second. Des discussions ont eu lieu sur des méthodes de sélection du matériel génétique de manioc à la lumière des facteurs déterminant la maladie et l'apparition des insectes et sur le rôle que ces facteurs jouent dans l'efficacité de la sélection. On a envisagé l'existence possible de variation pathogénique et de biotypes d'insectes qui détermineraient la durabilité de la résistance selon le temps ou le lieu. L'étude suggère les conditions optimales requises pour sélectionner efficacement le matériel génétique du manioc.

Cassava is native to Latin America. It was introduced into Africa during the last part of the 16th century and adapted quickly in the traditional tropical African farming systems. Since then, it has become a staple for the continent.

The major biologic constraints in cassava production in Africa are diseases and pests. The major diseases are cassava mosaic (CMD), bacterial blight (CBB), and anthracnose (CAD).

CMD has been observed in Africa and India. In Africa it is widespread and is noticed in all the cassava-growing areas (Hahn 1978), causing yield reductions of up to 90% in severely infected crops. The disease is transmitted by means of an insect vector (*Bemisia* spp.). The actual causal agent has not yet been identified, but a virus is suspected (Storey and Nichols 1938; Bock and Guthrie 1976; Rossel and Thottappilly 1978).

CAD caused by *Colletotricum* spp. is also an important stem disease in the grassland savanna regions of Central Africa, where soils are infertile and acidic (Terry and Goodman 1977).

The major pests of cassava in Africa are cassava mealybug (*Phenacoccus manihoti*) and cassava green spider mite (*Mononychellus tanajoa*). Cassava mealybug (CMB) has been reported from most of the major cassava-growing countries in Central and West Africa since its presence was first reported in Zaire in 1973 (Hahn and Williams 1973). Cassava green spider mite (CGM) also has become a serious pest throughout major cassava-growing areas in Africa since its presence was first reported from Uganda in 1972 (Nyiira 1975). It is believed that along with cassava both CMB and CGM were introduced from Latin America where they are native. These pests cause more damage in the dry season than in the rainy season and in areas with dry and poor sandy soils than in those with more humid soils.

In the traditional African agricultural systems where inputs are low, the use of vegetative propagating material infected with diseases and pests is quite common. CMB and CGM are widely disseminated by infested stakes, wind, and cassava leaves harvested for vegetables.

Because of the limitations in the use of chemicals to control the pests and diseases in Africa, the development of cultivars resistant to diseases and pests becomes the most appropriate and realistic approach for effective control.

The first steps, therefore, are to:

- Identify factors determining the incidence of diseases and pests upon which field screening

of breeding material for resistance can be based;
- Examine the factors that can influence the efficiency of screening; and
- Examine the role of pathogenic variation in the development of efficient and foolproof screening methods.

Factors Affecting Incidence of Diseases and Pests

Biologic Factors

Disease incidence depends on the availability of inoculum, which in turn depends on the density and activity of the vector (*Bemisia tabaci* in the case of CMD). For instance, CMD incidence was observed to be closely related to the number of whiteflies (Leuschner and Terry 1976). Detopping of shoots enhances CMD symptom expression. The young leaves are more susceptible than are older ones so that CMD symptoms decrease as the plant grows older. Incidence varies with the level of resistance of individual plants. The environmental conditions that apparently favour population buildup and activity of whiteflies are rainfall between 150 and 280 mm a month, temperatures within the range of 27–32° C, and solar radiation of 400 g-cal/cm^2 (Leuschner 1978).

It has been suspected that sucking insects increase CBB incidence. As plants become older, CBB symptoms in terms of tip dieback increase (Hahn 1978), and the older and lower leaves demonstrate more serious symptoms than do young leaves. However, as with CMD, the young shoots are more susceptible than are older ones to CBB, and incidence varies with individual plants depending on their resistance.

The succulent parts of young cassava plant stems are more susceptible to CAD than are the older parts.

Less damage from CMB and CGM is expected at lower populations of the pests and in the presence of their natural enemies.

Environmental Factors

Temperature affects CMD symptom expression; high temperature (35°C) suppresses symptom development (Chant 1959; Terry 1978b). Also, incidence is altered by lime application: 0.5–1.0 t/ha was shown to increase CMD incidence (Edward and Kang 1978). In acidic soils, CMD is less severe. Ambe-Tumanteh (1980) reported that soil nutrients, particularly N, P, and Na, are significantly associated with the severity of CMD incidence (r = 0.58, 0.54, and -0.51 respectively). CMD incidence is lower during the dry season, in areas at elevations higher than 500 m, and in areas with annual rainfall less than 900 mm or more than 1500 mm.

CBB severity is higher in areas where day and night temperatures average 20–25°C than in areas where they are at 25–30°C. Furthermore, it is higher in areas where temperatures at night are 15–20°C and during the day are 28–30°C than in areas where the night and day temperatures are, respectively, 22–25°C and 30–33°C (Takatsu et al. 1978). The optimum temperature for growth of both *Xanthomonas manihotis* and *X. cassavae* has been shown to be 30°C (Maraite and Weyns 1978). CBB incidence seems to be high in poor sandy soils during the rainy season.

CMB and CGM damage crops much more in the dry season than in the rainy season. Furthermore, they cause more damage to plants in dry and poor sandy soils than to those in wet, fertile soils.

Factors Affecting Efficiency of Screening

Breeding for resistance to diseases and pests aims at improving the cultivars' resistance in a wide range of environmental conditions and for a long period, the final goal being stable productivity. Screening in the field is generally based on phenotypic expression of disease symptoms by plants that are naturally infected by diseases and infested by pests. Screening is most reliable when done under environmental conditions that closely replicate cassava-growing areas, favour full symptom expression by the genotypes, and have adequate disease inoculum and pest populations. The optimum environment will magnify the differences between genotypes in the manifestation of the symptoms. The selection of the sites and seasons with the optimum conditions is very important for efficient field screening. The site(s) should as much as possible represent the major cassava-growing areas or regions in climate, soils, topography, biologic organisms (diseases and pests), and cultural methods. The environment of the site and seasons of screening should be as uniform as possible. The genotypes to be screened should also be at the most appropriate stage of plant growth for good infection by diseases and infestation by pests for better symptom expression.

To minimize the possible errors in screening or, in other words, to increase efficiency and to have the selected genotypes adapted over a wide range of environments, researchers should ensure that the genotype–environment interaction effect is small.

Is Resistance Durable?

Mosaic-resistant breeding materials from IITA have been tested in many countries in West Africa, Central Africa, East Africa, and India and have consistently shown resistance to CMD (IITA 1973–78). This absence of regional variation in resistance and the polygenic nature of resistance to CMD suggest that the resistance is durable for a long time in several localities but whether or not it will prove to be race–nonspecific depends on information on pathogenic variation that is at present not available (Hahn et al. 1980b). The allotetraploid and genetically heterozygous nature of cassava supports the theory that resistance to CMD is durable over localities and years. Results from the studies, particularly on pathogenic variation of CMD, merit further investigation.

Comparative studies among different American and African isolates of *X. manihotis* have shown that there are differences in their virulence (Lozano 1975). Maraite and Weyns (1978) reported that there are a few indications that *X. manihotis* (CBB) is different from *X. cassavae* (cassava bacterial necrosis), which was isolated from the material collected from Rwanda and Tanzania. However, whether these species differ in their reaction to different genotypes of cassava is not yet known. The CBB-resistant materials from IITA, when tested in Kenya, showed resistance (B. Beck 1980, personal communication). The material also showed resistance in Zaire. The CBB resistance developed at IITA thus appears to be effective in several localities. Resistance of cassava to CBB is polygenic. It has held true for the past 7 years in Nigeria. This finding suggests that the resistance is durable for a long time and in several localities. The pathogenic variation in CBB-causal organisms and the reactions of different genotypes of cassava to the possible strains and subspecies need further investigation.

No information on biotypes of CMB and CGM is available. Research in this area would be very useful in breeding tests for resistance to CMB and CGM and for biological control measures. Some cultivars at IITA are supposed to possess genes for resistance to CGM; the progenies raised from several parents produced at IITA showed resistance to CGM in Tanzania.

Screening Methods

In screening cassava breeding materials, researchers need to consider efficiency and should aim at stability of the resistance over years and localities.

Field screening for resistance to CMD must, therefore, be done in an environment where inoculum from diseased cassava is present, whitefly populations are high, and the average temperature is relatively low (below 30°C). It will be most effective in a locality where annual rainfall is 1000–1500 mm, elevation is lower than 500 m, average temperatures are about 20–25°C, and the soils have a pH 4–6 and are rich in N and P, poor in Na. Seedlings for screening need to be raised before the onset of the rainy season or early in the rainy season so that they are exposed to high disease pressure in the middle of the rainy season when whitefly populations are high, temperature is not very high, and plant growth is vigorous.

Detopping of the seedlings enhances CMD-symptom expression. The selected seedlings should be replanted in the following year as a clone for confirmation of resistance. Tests for CMD resistance for 2 years are sufficient in localities with high disease pressure, but at least 4-year tests are needed in localities where disease pressure is low, particularly in the high-altitude areas. Resistance to CMD has shown moderate to high heritability in plants tested under optimum environments; this finding suggests that selection for CMD resistance is effective and, in such environments, is possible at an early breeding stage.

CBB scores depend upon time of planting, age of plant, and time of observation (Hahn 1978) and have shown variation from year to year. CBB screening should be done in the rainy season when the rate of CBB symptom development and severity are high and when plant tissues are succulent. Seedlings should, therefore, be raised before or early in the rainy season as is the case for CMD-resistance screening. The correlation between CMD and CBB is significant and implies that selection for resistance to one of the diseases will result in resistance to the other. If heritability can be manipulated by the provision of favourable testing conditions and with better techniques for CBB screening, the gain in CMD resistance should parallel that in resistance to CBB. If CBB incidence is not high under natural field conditions, artificial inoculation with CBB provides better testing conditions. In the localities where both CMD and CBB are problems, screening for breeding materials for resistance to both diseases at the same time should be done. This method increases efficiency in screening and reduces expenses. Resistance to CBB, like that to CMD, has been shown to be moderately to highly heritable under optimum environments.

CMB and CGM are serious in the dry season. Therefore, screening of breeding materials for

resistance to both pests should be done during the dry season. One problem is that the effects of drought are often difficult to separate from the damage caused by the pests.

Resistance of cassava to CGM has been reported (Nyiira 1975; Msabaha 1975; and Hahn et al. 1980a) and has been more clearly demonstrated than has that to CMB; however some encouraging results have been obtained for the latter as well. For instance, mealybug has been reported not to colonize on a related *Manihot* species introduced from Brazil (IITA 1978); also there appear to be some clonal differences in damage caused by CMB in Zaire (IITA 1979), and remarkable varietal differences have been observed in recovery from CMB damage soon after the onset of the rainy season.

CASSAVA IMPROVEMENT IN THE PROGRAMME NATIONAL MANIOC IN ZAIRE: OBJECTIVES AND ACHIEVEMENTS UP TO 1978

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The Programme National Manioc (PRONAM) is a research and training project in cassava established by a cooperative arrangement between the government of Zaire and IITA. Progress made by PRONAM to assemble cassava germ plasm, to screen it for resistance to prevailing diseases and pests in Zaire, and to identify and multiply high-yielding, disease-resistant cultivars is reported in this paper.

Le programme national sur le manioc est un projet de recherche et de formation établi à la suite d'un accord intervenu entre le Gouvernement du Zaïre et l'IITA. L'étude décrit l'état des travaux entrepris par le PRONAM pour recueillir du matériel génétique de manioc, le sélectionner en fonction de la résistance aux principaux ennemis et maladies au Zaïre et les études sur l'identification et la multiplication de cultivars à rendement élevé et résistants aux maladies.

Established by a memorandum of accord between the government of Zaire and the International Institute of Tropical Agriculture, the Programme National Manioc (PRONAM) is a research and training project whose objectives are:

- Improvement of cassava in the Republic of Zaire; this includes breeding for resistance to diseases and pests and for improved root and leaf quality;
- Determination of some cultural practices that will enable cassava yield to attain an economic optimum; and
- Identification and training of highly motivated Zairois who will in the shortest possible time take over the running of the project.

This paper covers the cassava improvement efforts of PRONAM up to 1978.

Early in this program, it was recognized that cassava materials had to be made available at the M'vuazi station in Zaire for staff working there. Therefore, a breeder came to M'vuazi soon after arrangements for the establishment of PRONAM had been completed. The activities of the subprogram in breeding are nearing the last phase of a five- or six-phase scheme. Emphases have been on:

- Germ-plasm collection and field evaluation for resistance to major diseases and pests and other important characters including high-root yields and starch concentrations as well as low levels of cyanide in roots and leaves;
- Good consumer acceptability for *chickwangue*, *fufu*, and *Ndika* and palatable leaves with high levels of protein;
- Recombination and production of seeds from exotic cultivars and selected local varieties under isolated conditions; as polycrosses in open-pollinated fields; and as controlled crosses for incorporation of specific desirable characters;
- Preliminary yield trials at various locations of diverse ecological conditions;
- Advanced yield trials at various locations selected for their ecological diversity;
- Field demonstrations in farmers' fields through national agencies; and
- Multiplication of improved, disease- and pest-resistant, high-yielding cultivars now available at M'vuazi.

GERM-PLASM COLLECTION AND EVALUATION

About 196 clones of cassava were collected and maintained by Institut national pour l'étude et la recherche agronomiques (INERA) at M'vuazi before the arrival of the breeder. These, together with several thousands of seeds from various sources, became the base population for the PRONAM breeding program. Sources of the seeds were polycross recombinants from the 196 clones; about 100000 seeds of high genetic variability derived

Table 1. Disease rating of germ plasm at M'vuazi, 1975.

Source	Plants (no.)	% in classes:[a] 1	2	3	4	5
				CMD		
IITA–A	520	22	43	15	16	4
IITA–B	492	31	28	21	14	6
IITA–C	615	16	32	22	21	9
INERA–D	324	5	7	28	38	22
Farmers–E	165	0	8	30	29	33
				CBB		
IITA–A	520	28	26	17	9	10
IITA–B	492	26	39	28	7	11
IITA–C	615	19	44	20	11	6
INERA–D	324	9	16	21	36	18
Farmers–E	165	8	21	33	18	20
				Anthracnose		
IITA–A	520	13	29	44	7	7
IITA–B	492	15	32	25	19	9
IITA–C	615	21	27	34	13	5
INERA–D	324	7	11	42	12	28
Farmers–E	165	0	6	18	22	34

[a]Class 1 = no apparent symptoms; class 5 = death.

from 165 families supplied by IITA in 1974; and a further 2500 seeds from 138 families also supplied by IITA in March 1975. Local grains totaling about 50 000 seeds, seeds from IITA (50 000), and about 20 000 open-pollinated seeds derived from the 200 local clones were also established. An extensive screening of these populations was carried out during the first year of PRONAM operations in Zaire.

All the selections from the many seedlings established were observed to be susceptible to mealybug, a very serious pest in Zaire and elsewhere in Africa. Thus, it was recommended that the germ plasm be broadened further (Leuschner 1976), and about 100 000 seeds were provided to M'vuazi in March 1977. Most of the seeds were exotic species from South American countries including Venezuela, Colombia, Mexico, and Brazil. Introduction from these areas was important, as South America is the original home of the mealybug, and a source of resistance is most likely to be found there.

All the materials assembled at M'vuazi from 1974–76 were grouped into seven subpopulations designated according to their sources as:

- IITA families, in which one of the parents in the cross was known;
- IITA-A, which includes bulk seeds from preliminary yield trials in 1973;
- IITA-B, which includes bulk seeds of 58308 open-pollinated in 1973;
- IITA-C, which includes bulk seeds from preliminary yield trials' hybrids from 1973;
- INERA-D, which includes bulk, open-pollinated seeds from INERA clones from 1974;
- Farmers-E, which includes bulk seeds from farmers' fields; and
- INERA-F, which includes clonal selections from INERA collections.

Results of Screening and Yield Trials

The results of screening exercises (Table 1) indicated that resistance to cassava mosaic disease (CMD) and cassava bacterial blight (CBB) developed at IITA was maintained in the M'vuazi environment; that anthracnose was a more severe problem in Zaire than in Nigeria and that it was more serious in Bandundu region than in Bas-Zaire; that mealybug was a very important problem in Bas-Zaire, killing many of our resistant clones; that yield potential from 10 of 165 families was more than 50 t/ha. This yield potential was based upon 4-m seedling rows at plant spacings of 50 × 50 cm (Table 2). One clone, 02864, from the local collec-

Table 2. Summary of field distribution of cassava seedlings and clones at M'vuazi.

Yield range (t/ha)	IITA seedlings (no. of families)	Local clones (%)	Local clones (no. clones)	Local clones (%)
≥ 60.0	3	1.8	–	–
50–59.9	7	4.2	–	–
40–49.9	3	3.0	1	0.5
30–39.9	20	12.1	6	3.1
20–29.9	49	29.7	56	28.6
< 20.0	81	49.2	131	67.8

tion yielded more than 40 t/ha, and six others yielded more than 30 t/ha (Table 2).

Encouraged by these results, PRONAM staff considered it necessary to evaluate the clones at different locations. Details of results from that effort were given in the 1976 Annual Report (Table 3). From the clones evaluated, several lines have been selected for advanced yield trials at M'vuazi, Kiyaka, Vanga/Losekele, Kimpese, and Yangambi, multiplication for eventual on-farm trials, and distribution to farmers. Unfortunately, many valuable materials were lost because of poor supervision at some locations — Kikwit, Lowa, Bulungu, Mbanza-Ngungu, Boko, Gandajika, Kwilu-Ngongo, and Nkielelo villages. PRONAM had to decide to limit its activities to locations where there was adequate supervision and commitment. Therefore, new seeds received in 1977 were limited to M'vuazi and Kimpese for, respectively, positive and negative screening for resistance to mealybug; Kiyaka (Bandundu) and Gandajika (Kasai) for anthracnose; and Luberizi and Kivu for green spider mite. More rigorous screening was made possible by inputs from the pathologist who joined PRONAM in late 1976 and the entomologist who joined in January 1977 and whose major contribution was to advance PRONAM staff's understanding of the biology and mode of spread of mealybug (Nwanze and Leuschner 1977; Nwanze 1977; Nwanze et al. 1977; Ezumah and Knight 1977).

During the 1977–78 season, seedlings derived from Latin America were observed to be attacked by CMD. Pubescent cassava plants were tagged in an effort to find out whether hairiness provides physical resistance to mealybug attack. Results from that exercise showed both pubescent and nonpubescent plants to be heavily attacked by the mealybug, especially at Kimpese (negative screening). Scores were 4 and 5 in a range of 1–5, in which 1 stood for "no attack" and 5, "death." However, more than 90% of those scoring 4 were pubescent — possibly an indication of mild resistance attributable to hairiness.

Three selections of Brazilian origin with wild cassava characters, TMI 6134, TMI 6154, and TMI 6096, exhibited very high levels of resistance to colonization and development of mealybug. These sources of resistance are well recognized, and they will be used in future breeding work. A big setback is the inability of PRONAM staff to clone these materials. Seeds are readily produced, but CBB

Table 3. Mean root yield of clones at selected sites in Zaire (preliminary yield trials).

Location	Clones	IITA (kg/plant) Top 5%[a]	IITA (kg/plant) Top 10%	Control (kg/plant)	Ratio (IITA/Control) Top 5%	Ratio (IITA/Control) Top 10%
Alluvial soil; high water table						
M'vuazi/Mankewa	243	4.53 (12)	3.86	1.86	2.43	2.08
M'vuazi/Route P.V.	1105	6.67 (55)	4.92	2.95	2.34	1.73
Forest						
Vanga	525	4.15 (26)	3.09	2.84	1.46	1.09
Kiyaka Forest	183	4.27 (9)	3.23	2.13	2.00	1.52
Shrub, grass; deep topsoil						
Lowa	439	4.38 (22)	3.59	2.29	2.04	1.45
Derived savanna						
Kikwit	520	5.19 (21)	4.90	2.52	2.01	1.94
Poor sand						
Tonu	223	0.82 (11)	0.71	0.36	2.30	2.00
Kiyaka Plateau	1037	0.41 (52)	0.30	0.29	1.41	1.03

[a]Figure in parentheses is the frequency at 5%.

Table 4. Yield, quality of food preparations, and resistance scores of 11 varieties of cassava.

Varietal name	Identification	Yield (t/ha)	Quality				Disease, pest scores			
			Leaf	Fufu	Chick-wangue	General remarks	CMD	CBB	Anthrac-nose	Vigour
PRONAM 1	30555/3	31.4	Good	Very good	Good	Good	2	1	3	3
PRONAM 2	A 56	28.6	Good	Very good	Good	Good	2	2	2	3
PRONAM 3	30933/1	24.9	Good	Good	Good	Good	3	2	2	3
PRONAM 4	30179/2	26.6	Good	Very good	Good	Good	2	2	2	3
PRONAM 5	30697/272	21.2	Unac-ceptable	Very good	Good	Good	1	1	2	3
PRONERA 1[a]	Serial no. 02868	20.7	Good	Very good	Good	Good	3	2	3	3
PRONERA 2	154	17.8	Good	Good	Good	Good	3	3	2	3
PRONERA 3	108	22.7	Good	Very good	Good	Good	2	3	3	3
PRONERA 4	40	19.2	Good	Good	Good	Good	3	2	2	3
PRONERA 5	45	23.1	Good	Very good	Good	Good	3	3	3	3
PRONERA 6	146	15.8	Good	Very good	Very good	Good	3	3	2	3

[a]Based upon 3-year average at two locations and 5-year average at two locations.

attacks are often heavy and frequently result in fruit abortion.

HIGH ROOT YIELD AND GOOD QUALITY

The main criteria for selection have been high root yield, resistance to the major diseases and pests, high starch concentrations, palatability when prepared as *chickwangue* and *fufu* in addition to appearance — colour, odour, texture, and taste. Detailed results are presented in PRONAM annual reports of 1977 and 1978. Some PRONAM selections considered good or very good as *fufu* include A 157, 30068, 30225, 30344, 30280, 30014; as *chickwangue* are 30344, 30294, A 157, 30003, 30008, 30280, and many others. Those very good in terms of appearance include A 157, 30068, 30225, 30344, 30280, and many others.

In addition to 10 elite selections designated as PRONERA 1–5 (derived from the 196 INERA clones) and PRONAM 1–5 (derived from PRONAM exotics — Table 4), clones with high fresh root yields over 4 years were selected from the 15 best clones from the INERA collections (Table 5).

Table 5. Yield of 15 cassava clones in four seasons.

Clone	Mankewa			Mpalukidi	Mean	Standard deviation	On-farm trials (30 farmers, t/ha)
	1974–75 (t/ha)	1975–76 (t/ha)	1976–77 (t/ha)	1977–78 (t/ha)			
07 Amer Eala Ma 175	28.0	19.3	12.3	13.7	18.3	7.1	10.8
P. 2715 Yb 39/40	37.5	22.5	23.0	17.5	25.1	8.6	–
05746 Yb	27.5	18.7	25.0	15.5	21.7	5.5	21.2
0443/45/7×0299/15 Ma	14.5	23.8	18.0	17.1	18.4	3.9	18.6
Kandanga Malombe	12.6	18.2	15.7	17.1	18.4	5.4	21.6
Kengele 2	18.4	12.6	15.6	13.9	15.1	2.5	16.8
02864 S	48.3	31.7	22.8	16.1	22.4	12.1	10.0
Nzenza Yelese	16.4	11.9	18.8	19.9	16.8	3.5	17.6
5733	32.9	17.6	15.5	21.7	21.9	7.8	9.0
Kikiva	20.4	11.8	22.6	18.3	18.3	4.7	18.4
Mbuaki 2	15.5	16.5	15.5	15.9	15.9	0.5	11.6
Mbuaki (Belge)	15.6	21.7	18.9	19.8	19.0	2.5	22.4
02715 S Yb	11.5	17.4	23.4	20.3	18.2	5.1	13.2
4082/S Yb	24.7	19.2	21.4	18.6	21.0	2.8	8.0
(02864S × 0443) Ma 217	21.8	16.9	20.8	17.4	19.2	2.4	–

Table 6. Relative performance of some advanced yield trial selections at M'vuazi, 1977.

Clone	Fresh roots (11 months, t/ha)	Dry matter (%)	Dry weight (t/ha)	Starch (%)	Disease ratings (6 months)			Lodging (%)	Fresh roots (preliminary yield trials, 1975–76, t/ha)
					CMD	CBB	Anthrac-nose		
30344/8	48.5	30.7	14.9	23.9	2	2	3	30	25.6
F 154	43.5	27.2	11.8	20.9	3	3	2	25	21.7
30070/4	34.9	31.7	11.1	24.8	2	2	2	20	21.0
02864	30.8	32.6	10.0	25.6	3	3	2	30	24.7
30174/2	33.9	29.3	9.9	22.7	3	2	4	40	30.0
30225/1	30.1	32.0	9.6	25.0	2	2	2	10	20.2
30122/2	25.9	31.8	8.5	24.9	2	1	2	30	33.7
30122/3	24.8	34.3	8.5	27.0	1	2	2	20	18.0
30294/6	24.2	34.1	8.2	26.9	3	3	1	10	26.0
30429/7	23.8	33.0	7.9	25.9	3	3	2	0	20.1
30399/5	22.0	34.0	7.6	26.8	3	3	2	90	25.2
30344/6	21.3	35.0	7.5	27.6	2	2	2	40	48.6
F 45	24.7	29.5	7.3	22.8	3	3	3	40	26.8
30008/2	23.7	29.9	7.1	23.2	2	3	3	80	27.5
30213/5	20.3	34.7	7.0	27.4	2	3	3	10	14.2
F 120	19.8	34.4	6.8	27.1	3	2	3	25	18.3
30697/272	17.3	39.1	6.8	31.2	2	2	2	10	26.4
30280/3	22.0	30.7	6.8	23.9	2	3	2	50	23.3
30280/4	21.6	32.4	6.8	25.4	3	3	3	40	25.5
30070/2	20.4	33.0	6.7	25.9	2	2	3	35	30.0

Excellent PRONAM clones derived from the 1977 and 1978 advanced yield trials (see Rapport Annuel: PRONAM 1977 and 1978) are available (Table 6).

Evaluating Cassava Clones

Minikit plots are single 10 × 6 m plots established from 250 clones in cooperation with the Groupe économie rurale (GER). PRONAM's objective with the minikits was to involve GER in the selections. Useful information was obtained on farmers' preferences, and selections made were at the disposal of GER and a new cassava breeder.

In cooperation with GER, the 15 best INERA clones were made available to some 30 farmers. On-farm root yields were comparable with experimental yields for most of the clones, indicating the suitability of INERA clones for dissemination (Table 5).

Large-scale production has also been encouraged by PRONAM, which provided some clones, principally 02864 to Cies, JVL, Kolo, Sucrière, Kwilu-Ngongo. Large cassava plantations were established by these companies after 2 years of multiplication of the limited quantities of 02864 supplied by PRONAM. Average plantation yields greater than 22 t/ha have been reported by JVL.

Encouraged by persistent requests from various organizations, groups, and individuals for cassava stakes, the United States Agency for International Development (AID), at the request of the Zairian Département de l'agriculture, made available some funds for the establishment of 10–15 hectares for large-scale multiplication of clones in 1978. In 1979 about 42 hectares were added, bringing the total to 57 hectares. All clones planted in the concessions were acceptable in terms of quantity and quality: some produce high root yields and are of good vigour but are not resistant to the major diseases and pests.

The Future

PRONAM has the nucleus for genetic improvement of cassava in Zaire. Cassava collections of high genetic variability — both exotic and local — are available. Many of the earlier introductions among the 196 INERA clones and some of the local clones such as Mpelolongi originated in Brazil.

Hybridization between Mpelolongi and other local and exotic cassava varieties has resulted in enormous diversity in farmers' fields in Bas-Zaire. All these plus the available sources of resistance to CMD, CBB, anthracnose, mealybug, and green spider mite could result in production of a cassava

clone with multiple resistance to the major diseases and pests.

Preliminary screening reported in this year's review reveals that clones with very low levels of HCN in their leaves are also available at M'vuazi. These and other clones to be identified in future should constitute a valuable subpopulation for low-HCN cassava.

Several studies have shown that the cassava mealybug can be devastating and result in 50–80% root yield reductions (PRONAM 1978). Yet, related studies where cassava was planted early in the season in rich alluvial soil deposits with a high water table indicated much lower yield reductions (about 18%). Early planting and choice of relatively fertile soils for cassava production may help reduce the losses, although the release of resistant varieties is the long-term solution to the problem.

Cassava anthracnose remains a very important disease to which attention should be given. It is extremely serious in the derived sandy savannas and Kalahari sands of Bandundu and Kasai regions.

Advanced yield trials need to be conducted at locations with more ecological diversity than the ones now used. It is hoped that the expansion of PRONAM to include the multiplication and distribution phases and the government of Zaire–AID–IITA contract will mean that more centres for evaluation of PRONAM cassava will be financially and logistically viable and will be able to initiate more studies in diverse climatic zones. Paraprofessional training could be accelerated if centres other than M'vuazi were available.

The ideal cassava for areas where both roots and leaves are eaten is one that produces high root yield as well as high leaf yield during both rainy and dry seasons. Both roots and leaves must be of high quality and palatable. Should this ideal prove biologically unattainable, then the separation of the two desirable qualities may be investigated. The economics and acceptability of breeding one type of cassava for root production and another for leaf may be worth studying.

The most critical work seems to be the release of not more than five elite selections for multiplication and dissemination to farmers. The results so far at PRONAM indicate a high probability of obtaining reasonably acceptable selections. More testing is obviously needed and lots of work will need to be done to overcome the problems posed by mealybug, green spider mite, and anthracnose — the three major problems in which little achievement has been made to date by PRONAM.

ASSESSMENT OF CASSAVA CULTIVARS FOR EXTENSION WORK

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The vegetative qualities of TMX 30395 and Nwugo cassava cultivars planted in November 1978 were observed, and the root and gari yields determined when the plants were 12 months old.TMX 30395 was free of any disease symptoms and produced a close canopy that completely covered the ground at a spacing of 1 × 1 m by the time the crop was 6–7 months old. Nwugo had less than 10% CBB infection and the canopy was not as close as that of TMX 30395. TMX 30395 yielded more roots than did Nwugo with calculated yield of 21.4 t/ha against 17.8 t/ha. It also had thinner peel but higher lignification than did Nwugo. The lignification of TMX 30395 ultimately lowered the amount of gari that could be produced from this cultivar. The result spotlights the importance of assessing not only the disease resistance or tolerance and root yield but also the extraction rate of the directly consumable product of cassava roots before cassava cultivars are considered suitable to be released for extension work.

Observation des qualités végétatives de TMX 30395 et Nwugo, cultivars de manioc plantés en novembre 1978 et détermination du rendement en tubercules des plants de 12 mois. Aucune trace de maladie sur TMX 30395 et son feuillage couvrait complètement 1 m² de sol entre 6 et 7 mois. Chez Nwugo, moins de 10% de brûlure bactérienne et la voûte de feuillage n'était pas aussi dense que celle des cultivars précédents. Le rendement en tubercules de TMX 30395 a été supérieur à celui de Nwugo, soit respectivement 21.4 t/ha et 17.8 t/ha. La peau des tubercules était plus fine mais la chair plus ligneuse, ce qui a réduit la quantité de farine qu'on pouvait en tirer. Ces résultats mettent en évidence l'importance d'évaluer non seulement la tolérance ou la résistance aux maladies et la production de tubercules mais aussi la nécessité d'apprécier la quantité potentielle de produits de consommation avant d'introduire les cultivars sélectionnés.

Cassava is believed to have been grown in the coastal region of Nigeria as far back as 1668 (Dapper 1668), but its spread and importance in the country took nearly 3 centuries to materialize. A cassava improvement program began at the Federal Department of Agricultural Research, Moor Plantation, Ibadan, in 1954. The program's objectives were to:

- Collect as many local cultivars as possible;
- Introduce promising exotic cultivars;
- Hybridize and carry out trials;
- Select cultivars that were high yielding and had high dry-matter and starch content, low hydrogen cyanide content, disease (in those days, cassava mosaic virus) resistance or tolerance, and good consumer acceptability.

It was recognized early in the program that cultivars responded differently to different ecological zones and environments and that consumer preferences varied from one part of the country to another, depending on the environment, food preparations, and food habits. Hence, the country was zoned, and each zone had a centre and trial stations. Collections of local and introduced field cultivars and their hybrids were grown at each trial station for observation and selection. Similar observations and selections were carried out at the trial centres and at Umudike. Promising cultivars were subjected to consumer acceptability tests before being released for extension work.

When the Root Crop Research Unit was established at Umudike in 1961 as a substation of the Federal Department of Agricultural Research, it started with the objective, among others, of producing as quickly as possible a range of high-yielding, disease-resistant/tolerant cultivars with qualities acceptable to the consumer (Ekandem 1962). And because gari had become an important food item, its rate of extraction from a cultivar became one of the criteria used in the selection of cassava cultivars for extension work (Federal Department of Agricultural Research 1964).

Oloronto (53101), a local cultivar from Ibadan-Abeokuta area, was recommended for extension

Table 1. Extraction rates in processing 100-kg samples of roots from 12-month-old TMX 30395 and Nwugo for gari.

Cultivar	Weight of peeled root (kg)	Peel (% of total)	Weight of grated root (kg)	Weight of sieved flour (kg)	Waste (% of total)	Weight of gari at 12% moisture (kg)
TMX 30395	64.5	35.5	56.4	41.6	26.2	17.7
	63.3	36.7	55.0	38.2	30.5	15.9
	64.0	36.0	55.0	38.5	30.0	16.6
Mean	63.9	36.1	55.5	39.4	28.9	16.7
Nwugo	54.0	46.0	52.1	38.6	25.9	27.0
	54.0	46.0	51.7	38.6	25.3	27.3
	55.8	44.2	53.0	39.4	25.7	28.3
Mean	54.6	45.4	52.3	38.9	25.6	27.5

work for its high yield and consumer acceptability. It was also used in many crosses. In 1967, 60444, 60447, and 60506, all F_1 hybrids with 53101 as one of the parents were recommended for multiplication and distribution to farmers in all parts of the country (Umanah 1970).

When cassava bacterial blight (CBB), caused by *Xanthomonas manihotis*, became a serious disease in Nigeria in 1972, many cassava cultivars including 53101, 60444, and 60447 were found to be susceptible to the disease and were consequently withdrawn from extension work. As a result, only 60506 and Nwugo, a local cultivar, have remained for extension work in Anambra State.

To counter the effects of CBB, breeders have produced hybrids, including the TMX series, with resistance, and these have started being used in extension work. The quick reaction is commendable, more so, because within the last 3 years the very existence of cassava is being threatened by mealybug and green spider mite in some parts of the country. Nevertheless, one must not lose sight of the objective of consumer acceptability in breeding and selecting for disease and pest resistance, among other things.

My colleagues and I have, therefore, started at Nsukka to study the quality and consumer acceptability of the new promising hybrids produced at IITA and Umudike. A preliminary study involved TMX 30395 and Nwugo, which were grown in a randomized block design in November 1978. TMX 30395 was free of any disease or pest symptoms in the 12 months of growth. It also produced good canopy, which completely covered the ground, at a spacing of 1 × 1 m on the ridge, by the time the crop was 6–7 months old. Nwugo showed symptoms of secondary cassava mosaic and less than 10% CBB infection. Its canopy did not completely cover the ground.

The crops were harvested when 12 months old and the fresh roots weighed. TMX 30395 gave mean yield of 213.5 kg (2.14 kg/stand), which was significantly higher than the mean yield of Nwugo, 176.7 kg or 1.77 kg/stand, at the 1% level of probability.

Triplicate samples, each of 100 kg, were taken from each cultivar and processed into gari. TMX 30395 had thinner peel, higher lignification, poorer quality gari, and lower gari yield than did Nwugo (Table 1). Calculated gari yield per hectare showed that Nwugo produced more than 1 t/ha.

From 21.35 t/ha of TMX 30395, 3.58 t/ha gari were produced, whereas from 17.67 t/ha of Nwugo, 4.86 t/ha gari were produced. The quality of Nwugo gari, however, has yet to be determined.

Peeled Nwugo roots darkened if left for more than 3 hours, and this characteristic could adversely affect the gari colour where palm oil is not added.

The global interest in cassava in the last 2 decades has widened the gene pool available to cassava breeders. But even when high-yielding, resistant/tolerant hybrids have been selected from the large mass of germ plasm, consumer acceptability tests should be run as an essential aspect of an integrated cassava improvement program. Any hybrid or cultivar that fails this test should only be released if absolutely necessary and very cautiously and selectively.

A repeat performance of what nearly rendered ineffective the great efforts to save maize in West Africa from the devastating American maize rust (*Puccinia polysora*) in the mid-50s must be avoided. The onset of American maize rust in West Africa in 1949 gave rise to extensive introduction of resistant maize varieties with hard, flinty grains. Such grains are not acceptable to consumers in certain parts of Nigeria. A majority of the farmers continue to grow local varieties into which, fortunately, notable introgression has occurred. Such favourable change is extremely remote with cassava.

BREEDING CASSAVA RESISTANT TO PESTS AND DISEASES IN ZAIRE

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Cassava in Zaire is attacked by three major diseases, namely mosaic, bacterial blight, and anthracnose. Recently two pests, mealybug and green spider mite, have attained considerable importance in cassava production. Stem dieback observed in 1978 is now becoming important with some varieties at M'vuazi. The causal agent for the disease is not yet known. Keeping in mind the sequential appearance of the diseases and pests in cassava and the factors favouring their development, I developed a procedure for a thorough screening of the breeding material. The results obtained with this procedure allowed the identification of clones with tolerance to diseases. Some plants showing least damage by mealybug have been identified and are again being screened to confirm the results. Resistance to mealybug appears to be very low in the population tested. Success in artificial hybridization between wild cassava plants possessing genes for resistance and cultivated types has been obtained.

Au Zaïre, les trois principales maladies qui s'attaquent au manioc sont la mosaïque, la brûlure bactérienne et l'anthracnose. Mais tout récemment, les cochenilles et les teignes sont venues ravager les récoltes. La rabougrissement observé depuis 1978 à M'vuazi s'étend à d'autres variétés et la cause de la maladie est encore inconnue. Une méthode de sélection du matériel génétique a été mise au point en fonction de l'apparition séquentielle des maladies et des ennemis du manioc en prenant en compte les facteurs favorisant leur développement. Ce procédé a permis d'identifier des clônes tolérants aux maladies. On étudie également plusieurs variétés moins affectées par les cochenilles afin de confirmer ces résultats. Mais la résistance semble très faible dans la population étudiée. Cependant, les chercheurs ont réussi l'hybridation de plants de manioc cultivés avec des plants sauvages possédant des gènes de résistance aux cochenilles.

Cassava in Zaire is seriously attacked by three major diseases, namely bacterial blight, mosaic, and anthracnose. In addition to the diseases, two pests, mealybug and green mite, have attained considerable importance in cassava production.

Cassava bacterial blight (CBB) was first observed in Bandundu region of Zaire in 1970 (Ezumah and Sebasigari 1976). Since then it has spread to all the regions of Zaire. Mosaic has been prevalent on cassava throughout the republic in various degrees of seriousness probably since cassava introduction. Anthracnose is also recorded in all the regions but is known to be particularly serious in Bandundu region. In the past 2 years, stem dieback has been observed on most of the cassava varieties at M'vuazi. It normally appears only in the old plants and in the dry season. The actual causal agent for this is not yet known. This year the disease has attained a serious proportion in the material at M'vuazi.

Of the two pests, mealybug was first recorded on cassava near Kinshasa in 1973, but it was not widespread at that time. By the year 1976 it became very serious and almost threatened the production of cassava in Bas-Zaire region. Now it is prevalent in scattered pockets in most of the southern regions of Zaire. Green spider mite, which was first recorded in Kivu region, was supposed to have been introduced from Uganda. This pest has now been observed in all the regions of Zaire.

The main vehicle of the fast spread of diseases and pests in Zaire is the uncontrolled movement of infected planting materials from one place to another by business people and the farmers.

IMPORTANCE OF DISEASES AND PESTS

The diseases and pests, particularly CBB, mosaic, mealybug, and green spider mite, cause reduction in root yields as well as cassava foliage. Root-yield losses varying from 57 to 90% in susceptible cassava varieties have been reported from different places (Terry 1978). An average root-yield reduction of 50% from mosaic-infected fields has been reported by Jennings (1970).

Mealybug has been reported to cause a yield reduction varying between 54 and 85%, depending on plant age at infestation (PRONAM 1979).

CBB in its severe form causing leaf drop and stem dieback seriously affects the supply of cassava leaves during the rainy season. The cassava leaves are widely consumed in Zaire as a source of protein. On top of this, mealybug and green spider mite appearing in the dry season restrict the growth of terminal shoots and thus further restrict the foliage production.

The diseases and pests causing losses in root yields and leaf production appear sequentially at different plant growth stages. Although cassava mosaic has been observed even at the beginning of plant growth, blight is generally considered to appear first (February–March) and is followed by mosaic that attains its peak expression in May–June. Anthracnose normally begins to appear in June–July when plants are 6–7 months old, and it continues to spread through the dry season. The dry season also favours infestation by pests. Green spider mite first appears soon after the beginning of the dry season (June–July) when the weather at M'vuazi is relatively cool (18–22°C). Later, in August, when the temperature rises, mealybug infestation starts and continues till the beginning of the rainy season in October.

Keeping in mind the sequential appearance of the diseases and pests throughout the growth of cassava and the advantage of vegetative means of cassava propagation, I developed a procedure for thorough screening of cassava seedlings to identify those that have resistance to three major diseases and mealybug (Singh 1979).

The procedure consists of planting the seed material at the end of October with the onset of the rainy season. Artificial inoculation of 1–2-month-old seedlings is done in December with a syringe or with the tong method (Pacumbaba 1979). The symptoms begin to appear after 3–4 weeks, but wilting of leaves and dieback take a longer time. Therefore, final screening against CBB is done in the month of March. Susceptible plants are rogued out, and in April the remaining plants are detopped to initiate new growth. Symptoms will be clearly expressed. Only the plants showing serious leaf deformation are rogued out. Remaining plants are then screened for anthracnose under natural infestation. As the plants grow older, the susceptible ones begin to show stem cankers and defoliation. Scoring for anthracnose is done as late as harvest time along with final plant selection.

For screening against mealybug, one obtains stakes from the detopped plants and plants them separately in a nursery, taking care that their family identity is maintained. Stakes planted at the end of April have a month of rainy season for sprouting and growth. The following dry season restricts their growth so that they are most susceptible to infestation. In August, one artificially infects the plants by leaving a mealybug-infested twig on the growing tip of each plant in the nursery. The insects move from the twig to the growing tip and start developing a colony. Screening against the pest is done at the end of September or beginning of October before the rainy season. Plants are scored against mealybug on 1–5 scale (PRONAM 1977).

SCREENING AGAINST DISEASES

Of 13970 plants inoculated artificially with CBB, 7392 plants died from the disease. These plants were rogued out. The remaining plants showed some symptoms but no dieback. These plants were detopped for mosaic screening. Some of the detopped plants did not recover and died. Scoring for mosaic revealed very few plants with scores of 4 and 5, the majority being in the 1–3 range. These were retained for screening against anthracnose. Later scoring of plants against anthracnose was done under natural infection, and the plant population showed considerable variation. The results showed that a large proportion of plants fell into scores of 1 and 4 (1208 and 1427, respectively), whereas the frequencies for scores 2, 3, and 5 were 207, 319, and 327, respectively. Because screening against anthracnose has been done under natural infection, all the plants showing a score of 1 may not be resistant, and the results need confirmation. The score of 4 for 1427 plants does not necessarily represent very serious damage because it was recorded even for those that only showed cankers on the top third of the plant but not in serious form.

After the disease screening, single plants showing good plant vigour, tolerance to three diseases, and good root formation were selected for further evaluation, and 438 clones established from the single plants selected from the nursery were screened in 1980 against three diseases (Table 1).

A majority of the plant selections made in the seedling nursery for resistance to CBB and anthracnose have been effective. Selections made for resistance to mosaic, however, showed considerable variation, and a good number of these plants showed scores as high as 4 and 5. The appearance of plants with scores of 4 and 5 reflects the high environmental influence in masking the expression of mosaic symptoms, or, in other words, the character has very low heritability.

Table 1. Scoring of plants at 3 and 6 months in the clonal nurseries against CBB, mosaic, and anthracnose.

Disease	Disease score[a]				
	1	2	3	4	5
	Nursery I plants				
CBB	45	129	41	3	0
Mosaic	47	76	88	8	0
	(46)	(55)	(99)	(19)	(0)
Anthracnose	156	1	32	29	1
	(127)	(4)	(46)	(39)	(3)
	Nursery II plants				
CBB	83	71	37	21	7
Mosaic	31	55	64	50	19
Anthracnose	202	13	4	0	0

[a]Figures in parentheses are the scores for 6-month-old plants.

SCREENING AGAINST PESTS

The mealybug screening nursery established in April 1979 was infested artificially in August, and plants were scored in October before the rains. Single-plant scoring showed that 42 and 1939 plants, respectively, showed scores of 1 and 2, whereas 1906, 1850, and 757 plants, respectively, showed scores of 3, 4, and 5.

It is clear that resistance to mealybug is very rare. Only 0.07% of plants showed no plant damage. Single-plant selection was based on degree of infestation and plant damage. The selected plants (123) belonged to 85 families. Two families, TMS 3055 × P2 and NR 7718, comprised 7 of 56 and 5 of 13 plants with least damage, whereas other families constituted only 1 or 2 plants. Five stakes from each of the selected plants were planted in April 1980 for reinfestation to confirm their level of resistance. Each plant in these clones has been infested and will be scored in October for more reliable estimates.

In addition to the search for resistance in cultivated cassava, a crossing program has been initiated so that gene(s) for resistance to mealybug can be transferred from wild cassava to adapted cassava varieties. Some success in hybridization has been attained. It is noteworthy that the wild cassava is not amenable to cloning through stakes.

A clonal nursery of 1460 lines was screened against infestation by green spider mite. The results showed that 51 and 221 clones respectively were rated with scores of 1 and 2, whereas 538, 348, and 301 clones were, respectively, rated with scores of 3, 4, and 5. The above results indicate that resistance to green spider mite appears to be more frequent than is that for mealybug (PRONAM 1979).

Results obtained so far from the screening clearly indicate the possibility of obtaining clones that will have a reasonable level of resistance to all the three diseases and pests combined with good yield potential.

SELECTION OF CASSAVA FOR DISEASE AND PEST RESISTANCE IN THE CONGO

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A brief overview of the screening work in the cassava improvement program in the People's Republic of Congo is provided. Major emphases of the program are bacterial blight, anthracnose, and mealybug. The base for such work is a living collection of cassava, the nucleus of which has now been established. To date 100 local cultivars have also been characterized. Screening for resistance to the three "plagues" has been under way for 4 years, and some preliminary results are encouraging. Shortages of funds, qualified personnel, and equipment have hindered the program.

Bref aperçu des travaux de sélection réalisés dans le cadre du programme d'amélioration du manioc de la République populaire du Congo. La recherche s'attache surtout à la brûlure bactérienne, à l'anthracnose et aux cochenilles. Les expériences sont effectuées sur une collection vivante de manioc dont un noyau solide a déjà été formé. L'étude des caractères de 100 cultivars locaux est déjà terminée. La sélection pour la résistance aux trois principales "plaies" commencée il y a 4 ans donne déjà des résultats encourageants. Mais l'avancement des travaux est ralenti par le manque de fonds, de personnel qualifié et d'équipement.

The principal objective of the cassava improvement program in the Congo is the selection of cassava varieties that will be resistant to bacterial blight and other diseases and pests associated with its cultivation. However, as a parallel activity, my colleagues and I are also seeking varieties that will be flexible enough to adapt to various ecological environments — varieties adaptable both to modern state farm cultivation and to the practices of the traditional farmer. In the ensuing stages, we will also be seeking varieties having a high nutritional value.

Two diseases and one pest plague cassava production in the Congo — bacterial blight, anthracnose, and mealybug; the severity of their attacks is such that at one time there was a cassava shortage. It must be noted that their geographic distribution varies. In the forest zone, bacterial blight is not a major problem, nor is the mealybug. In the savanna zone areas where rainfall is less than 1200 mm also bacterial blight is not a major problem, but there are a great many mealybugs (as the dry season sometimes lasts more than 5 months). In savanna zone areas where rainfall is greater than 1500 mm, bacterial blight and anthracnose are running neck and neck and are widespread. In organizing the selection program, therefore, we had to take into account these ecological differences. We established two selection locations, the main one being Malela at Loudima, and the second Mbé, north of Brazzaville.

VEGETAL WORK MATERIAL

The first problem was to establish the vegetal work material. Before undertaking any selection work, one must have a variety of vegetal material. At the same time as we considered the introduction of foreign varieties, we thought it would be interesting and indeed wise to know our own cultivars. To this end, we searched various areas of the country and, using local cultivars, established a living collection of cassava. In view of the much more serious manifestation of bacterial blight in the Mbé area, we judged it best to establish the Mbé area collections at Mbé instead of bringing them back to Loudima; this further justified the creation of this second selection location.

The primary task was the characterization of the local cultivars (description, measurements, etc). We have now characterized a living collection of 100 local cultivars. This number will no doubt be much higher when all zones of the country have been searched, because the Congo's geography is such that many cultivars have been brought in by border populations from neighbouring countries where cassava is also a staple.

Stakes of some cassava varieties had been introduced by a cassava farm before the cassava improvement program was established; examples are the Togo variety "Kataoli," the Madagascar variety "H54," and several Zairian varieties. These varieties also form part of our living cassava collection.

As part of our program, we also introduced improved genotypes from IITA. Since November 1976 we have begun selections from the population of clones created with seedlings from IITA genotypes; in Loudima we are attempting to obtain varieties resistant to bacterial blight, drought, and mealybugs, and in Mbé varieties that are resistant to bacterial blight and also show a good reaction toward anthracnose.

SCREENING

Screening was carried out over a 4-year period. Tests compared performances of varieties in different locations. We obtained valuable information on a few cultivars that turned out to have fairly high production potential, as well as good reaction to bacterial blight. We are also beginning to obtain good results with the clones from IITA; among these are MA34, MA66, MA433, and MA255 at Loudima and MB17 at Mbé. However, these results were obtained from screenings in which the diseases developed naturally — that is, no artificial inoculation or infestation was undertaken. Each selection location's ecological conditions governed disease and pest spread.

Evaluation of the attacks was done from observations of the symptoms of the respective diseases. The scale of values ranged from 0 to 5, with 0 being no visible symptoms and 5, severe attack.

Observations of each attack were made at various periods of critical attack by the diseases: between March and May for bacterial blight and anthracnose at Loudima, when the plantation is between 5 and 8 months old; in December or January for mosaic disease, which is especially serious when the plantation is 3 months old (a little later one may observe a regression of the disease); and in September for the mealybug, the cassava being 10 or 11 months old.

PROBLEMS

There were many problems, especially as the program was being started during the early stages of our research. Collection of local cultivars was not comprehensive, and many areas have not been investigated. Our project for collecting local vegetal material received the support of the ACCT (Agence de coopération culturelle et technique), which kindly agreed to finance a search throughout the country, for the creation of a base for genetic resources for cassava for Central Africa. The annual reproduction of the collection, the maintenance of the experiments and collections, and the maintenance of two or more antennas are dependent on sufficient financial support, adequate equipment, and a technical staff that is relatively familiar with the work. These were often lacking during the course of our work; in future, support will be provided by IDRC.

CONCLUSIONS

The program for cassava improvement in the Congo is still young. The varieties mentioned in this report are listed for information only, because it is still too early to judge their full potential. We hope, therefore, that this program will continue to enjoy the support of the government and of international organizations, so that it may succeed and produce the best results.

This paper was originally French; with the author's permission, it was translated into English for inclusion in these proceedings.

SOME CHARACTERISTICS OF YELLOW-PIGMENTED CASSAVA

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Cultivated cassava with yellow-pigmented root flesh is called by different names by the Akans of Ghana. It has long been among selected cassava varieties in Ghana. The flesh is yellow when fresh and boiled. *Bankye Borode* (BB) is used in preparation of *fufu* and imparts the desired yellowish colour that is otherwise provided by the more expensive plantain. Yellow gari prepared from this type of cassava is so popular that some gari-makers imitate it by either adding palm oil to gari from white cassava or by scorching white cassava. Cassava clone BB-1 (UST 12-8) that was apparently mosaic-free was obtained from one of the IITA selections, 1976 TMS 30572, planted in Kumasi (forest zone) in August 1977. It was pigmented, and the quality of *fufu* prepared from it was good. However, when the same clone was planted for the first time in Legon, Accra (coastal savanna zone), in March 1979 the *fufu* quality was poor, indicating an effect of environment on the cassava. Accumulation of the pigment in the roots was observed to increase with time. It is likely that the pigmented cassava has higher vitamin A and calcium contents than does the white one. Mosaic-free and clean stakes were produced from some individual stakes of the clone BB-1. Besides BB-1, five more pigmented local clones have been collected from different parts of Ghana for studies that will include the effect of environment on the quality of cassava, the nutritional value of pigmented cassava, and the nature and mode of accumulation of the pigments.

Les Akans donnent plusieurs noms différents au manioc à chair jaune qu'ils cultivent au Ghana. Ce sont les racines fraîches et bouillies qui prennent cette couleur jaune. *Bankye Borode* (BB) entre dans la préparation du fou-fou à qui il donne cette teinte obtenue seulement par le broyage de plantains beaucoup plus coûteux. La farine jaune provenant de ce type de manioc est tellement populaire que certains meuniers vont jusqu'à ajouter de l'huile de palme à du manioc blanc ou griller du manioc blanc pour lui donner cette couleur. Le clône de manioc BB-1 (UST 12-8) apparemment exempt de mosaïque, provient de sélections de l'IITA, 1976 TMS 30572 plantées à Kumasi en août 1977 (zone forestière). Cette variété était colorée et elle donnait une bonne qualité de fou-fou. Cependant lorsque ce clône a été introduit pour la première fois à Legon, Accra (zone côtière de savanes) en mars 1979, la qualité de fou-fou obtenue a été médiocre, effet de l'environnement sur le manioc. Mais on a pu observer une augmentation constante de la pigmentation dans les racines. Il est possible que le manioc coloré ait une teneur en vitamine A et calcium plus élevée que le manioc blanc. On a pu obtenir des plantes saines et exemptes de mosaïque chez quelques individus du clône BB-1. En août, on a réussi une collection de cinq clônes locaux encore plus colorés dans différentes parties du Ghana qui seront étudiés en fonction de l'influence du milieu sur la qualité du manioc, de la valeur nutritionnelle du manioc coloré et de la nature et du mode de concentration des pigments.

Cultivated cassava with yellow-pigmented root flesh is called by different names by the Akans of Ghana who form the majority of the population. These names include *Bankye Borode*, literally meaning cassava plantain because the colour of the cassava resembles that of the edible portion of plaintain; *Bankye Kokoo*, meaning cassava yellow or red because of the pigmentation; *Bankye Nkani*, meaning cassava yellow yam because the colour resembles that of *Dioscorea cayenensis*; and *Bankye Nkamfo* also because the colour resembles that of *D. dumetorum*. The Ewes too call it *Agbeli Kani* and *Agbeli Dze*. *Bankye Borode* (BB) is the name adopted in this paper.

The existence of these names both in the local languages and in the 1930 and 1960 local cassava collections (Doku 1969) indicates that the yellow-pigmented cassava has long been among the varieties selected in Ghana.

BB is used in the preparation of *fufu*, and it imparts the desired yellowish colour resembling that of plantain. At present, Ghanaians prepare plantain *fufu* by pounding a small quantity of the expensive plantain with a large amount of the relatively cheap white cassava; the cassava facilitates pounding, increases the quantity, and still maintains the characteristic yellow of the *fufu*. BB, therefore, is a cheap substitute for the plantain.

This quality makes the cassava very popular, especially with restaurants or "chopbars" serving plantain *fufu*. In the absence of BB, some restaurants try to achieve similar results by either adding palm oil when pounding white cassava or by using partially fermented cassava.

BB is also popular with many Ghanaians, even among the Akans who have preferred cocoyam and plantain and have been reluctant to take cassava in the form of *fufu* and *ampesi* (Doku 1969). These people still prefer to have some plantain in their *fufu* to provide colour. Some of these people are so colour conscious that in the absence of BB and plantain, they cook white cassava with the leaves of Christmas bush *Alchonea cordifolia* (Akan: *Ogyamma*) to make the cassava yellow (S.O. Mensah, personal communication).

Gari is another cassava product in which BB plays an important role. A yellow gari prepared from the pigmented cassava is so popular with some Ghanaians that gari-makers imitate it by roasting white cassava with more palm oil than is needed in the frying pan. Sometimes they produce yellow gari by scorching white cassava.

Despite its importance in Ghana, BB has not been given much attention in the available literature, although its name is mentioned. The nature and mode of accumulation of the pigment(s) as well as the nutritive value are still unknown. My work has been undertaken to fill the gap.

MATERIALS AND METHODS

Stakes of a yellow-pigmented cassava clone planted originally in Kumasi in July 1977 from a seed were planted in the Crop Science Department garden in Legon, Accra, in March 1979. This clone (UST 12-8) belonged to the International Institute of Tropical Agriculture (IITA) family 1976 TMS 30572 and was the only BB found among 223 plants representing 31 families that survived the 12-month growing season in Kumasi. Its leaves were clean, indicating a possible resistance to both the cassava mosaic disease (CMD) and the cassava bacterial blight (CBB) (Oduro and Asare 1978). The clone, now designated BB-1, meaning *Bankye Borode* no. 1, was planted in Legon primarily for multiplication and for some initial observations on its continuous resistance to CMD and CBB, yield, *fufu* quality, and the mode of pigment accumulation.

Besides BB-1, some yellow-pigmented local clones have been collected from different parts of Ghana and planted at Kwabenya near Legon for multiplication and similar preliminary observations. These clones are BB-2, obtained from Professor E.V. Doku's cassava museum at Legon. The clone was originally collected from Mampong in the Ashanti Region under the name *Bankye Kokoo*; BB-3, from Chiraa in the Brong Ahafo Region; BB-4, from Batabi in the Eastern Region; BB-5, from Bieni in the Eastern Region; and BB-6, from Asuboa in the Eastern Region (called by some *Bankye Nkani*).

RESULTS AND DISCUSSION

Movement of CMD appeared impeded in the BB-1. When 47 stakes of the clone were planted in the Legon garden in March 1979, 19 of them produced stems with mosaic symptoms from about the 3rd to the 12th month. Stems produced individually by the 19 ranged from one to five. When more than one stem was produced, at least one of the stems was diseased (Table 1). This observation gives rise to questions about the systemic nature of CMD regardless of the source of inoculum. However, further investigations are necessary before any meaningful conclusions can be drawn.

During the dry season (December 1979), there

Table 1. Occurrence of mosaic and clean stems produced by some individual stakes of cassava clone BB-1.[a]

Stems produced/ stake	Stakes	Diseased stakes	Diseased stakes with: 1 stem diseased	2 stems diseased	3 stems diseased
1	7	2	2	–	–
2	16	7	6	1	–
3	16	7	3	2	2
4	6	2	2	–	–
5	2	1	1	–	–

[a]BB-1 meaning *Bankye Borode* no. 1 selection is a new designation for UST 12-8 obtained from IITA seed 1976 TMS 30572. Clean stakes were collected from Kumasi and planted in Legon in March 1979. Data were collected from about 3 to 12 months.

appeared to be mealybug infestation of the plants (BB-1) in the Legon garden, resulting in defoliation and a sooty appearance of the foliage. Other local varieties of cassava and some beans in the garden had the same infestation; however, mealybug was not observed when BB-1 was planted for the first time in Kumasi. Accumulation of the yellow pigment(s) in the roots appeared to increase with time. When 6-month-old plants (BB-1) were harvested, they showed traces of the pigment(s), but those harvested at the end of 12 months were intensely pigmented. Detailed studies on the nature and mode of accumulation of the pigment(s) are necessary.

Environment appeared to affect the quality of cassava root products, possibly starch. When BB-1 was planted in Kumasi (forest zone) in August 1977, the *fufu* from its product was elastic. However, when the same clone was planted for the first time in Legon (coastal savanna zone) in March 1979, the boiled roots were hard and soggy and the *fufu* was inelastic and, therefore, of poor quality. Perhaps, the quality will improve when the clone is adapted to the savanna conditions. Further investigations are essential and need to include all the available clones, planting being done simultaneously in the forest and savanna zones.

Yellow-pigmented cassava is likely to be more nutritious than white. Although I did not attempt, in this preliminary study, to determine the nutritional value of the cassava, some findings reported elsewhere suggest that BB has high calcium and vitamin A contents (Jones 1959). In data reported from Togo, yellow gari was shown to have 83 mg of calcium, whereas white cassava had about 46 mg (Jones 1959). However, it was not stated whether the yellow gari was naturally pigmented by the cassava or was artificially coloured. The Food and Agriculture Organization (FAO) data also showed that white, pale yellow, and deep yellow varieties of sweet potato had 80, 500, and 7000 international units (IU) of vitamin A content, respectively, and that cassava had traces. The type of cassava used in the analysis was not stated. Perhaps, if a yellow-pigmented cassava had been used, its vitamin content would have been increased. Because both white and yellow varieties of sweet potato exist, it is not strange to have a similar situation in cassava. Indeed in cassava two different grades of yellowness exist.

There was only one adverse comment on BB in a survey of more than 100 people. One respondent disclosed that whenever her mother ate it, especially as *ampesi* she had diarrhea. This complaint is at times also leveled against white cassava or cocoyam eaten as *fufu*. Isolated observations such as this, however, should not be discarded, and further studies should be undertaken on all available clones of yellow-pigmented cassava.

CASSAVA: ECOLOGY, DISEASES, AND PRODUCTIVITY: STRATEGIES FOR FUTURE RESEARCH

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Agroecological factors with special reference to climate in the African cassava belt are reviewed. The direct effects of climate on the severity of cassava diseases and the survival of cassava pathogens are examined, examples being taken from the experience of cassava bacterial blight in Africa. A proposal for future research strategies in cassava pathology focusing on the ecology of cassava pathogens and other factors limiting cassava productivity in Africa is presented.

Revue des facteurs agro-écologiques de la ceinture du manioc d'Afrique, particulièrement ceux qui se rapportent au climat. L'étude des effets directs du climat sur la gravité des maladies du manioc et la survie des pathogènes est rapportée dans cette communication illustrée par des exemples tirés de l'expérience de la brûlure bactérienne en Afrique. Il est proposé des stratégies de recherche sur la pathologie du manioc, centrée sur l'écologie des pathogènes et sur les autres facteurs qui limitent la productivité du manioc en Afrique.

All major epidemics have one major characteristic; they are an intensified union of a crop and a pathogen following either genetic, temporal, spatial, geographic, or climatic separation (Buddenhagen 1977). In Africa, the type of cassava epidemic that occurs is generally described as new-encounter disease. New-encounter cassava diseases may be subdivided into three classes: those that result when cassava is introduced into a region, those that result when cassava pathogens are introduced into a major cassava-producing region, and those that result when both cassava and its pathogens are introduced separately, usually with the crop being introduced first.

Data from the Americas (CIAT 1980) have indicated that when local, regional, or newly developed cassava genotypes are evaluated for their productivity under different agroecological conditions, significant cultivar, biotic, and ecosystem interactions occur. Also data from Nigeria (Hahn, S.K., personal communication) have shown significant variations in yield performance of two improved varieties in environments that vary widely in seasonal and total precipitation, soil fertility, and disease incidence and severity (Table 1).

THE AFRICAN CASSAVA BELT

Cassava is a short-day plant, and its distribution in Africa is therefore largely confined to the areas between latitudes 15° N and 15° S (Jennings 1970). The extent of this African cassava belt is limited geographically not so much by temperature as by rainfall, and the boundaries of its cultivation appear to correspond roughly, although not precisely, to those areas where mean annual rainfall exceeds 750 mm (Jones 1959).

On a regional basis, there are some marked ecological features that characterize the major zones within the cassava belt. Thus this belt can be subdivided on the basis of rainfall distribution and temperature variations into the tropical wet zones and the tropical wet and dry zones.

THE TROPICAL WET ZONES

The tropical wet zone typically exists in a belt extending between 0° and 5–10° on both sides of the equator. It is marked by heavy precipitation during the major part of the year, usually ranging from 2000 mm to well over 3000 mm.

Temperatures are uniformly high, with annual means usually 25–27°C and little seasonal variation. Average monthly maximum and minimum temperatures are about 31°C and 25°C, respectively, and the difference between the hottest and coolest months is generally less than 5°C (Brook 1979).

The tropical wet climates may be further divided, on the basis of their seasonal rainfall distribution, into the equatorial zone, where the abundant rainfall is relatively well distributed throughout the year

Table 1. Cassava yield and reaction to CBB and CMD in four locations in Nigeria.[a]

Variety	Location and rainfall (mm)	1977 Yield (kg/plant)	1977 CBB	1977 CMD	1978 Yield (kg/plant)	1978 CBB	1978 CMD	1979 Yield (kg/plant)	1979 CBB	1979 CMD
TMS 30572	Ibadan; 1270	1.49	1.5	1.8	1.69	1.4	2.4	1.69	1.5	2.3
TMS 30572	Onne; 2500	2.42	2.5	1.0	1.75	1.0	1.4	1.39	1.5	1.1
TMS 30572	Warri; 2600	0.48	1.5	1.0	0.77	1.0	1.7	NA	NA	NA
TMS 30572	Mokwa; 1100	1.73	1.0	1.0	NA	NA	NA	1.18	1.0	1.1
TMS 30555	Ibadan; 1270	1.09	1.5	1.9	1.54	1.5	2.5	2.41	2.0	2.5
TMS 30555	Onne; 2500	1.78	3.0	1.8	0.92	1.0	1.8	1.11	1.3	1.5
TMS 30555	Warri; 2600	0.45	1.0	1.0	0.70	1.0	3.0	NA	NA	NA
TMS 30555	Mokwa; 1100	1.41	1.0	1.4	NA	NA	NA	0.74	1.0	1.5

[a]CBB and CMD scores are based on a scale of severity, increasing from 1 to 5; NA = not available.

and the moist monsoonal zone, where rainfall is also abundant but where a short dry season of not more than 2 months normally occurs.

The Tropical Wet and Dry Zones

The tropical latitudinal position of the tropical wet and dry climate is from 5–10° to 15–25° on either side of the equator. In this climatic zone, annual precipitation is generally less than in the tropical wet zone, and rainfall is more seasonal, with distinct wet and dry seasons. Total precipitation is usually between 1000 mm and 1500 mm with a dry season of at least 2 months, increasing in length with distance from the equator (Brook 1979).

Although the temperature characteristics in this climatic zone are quite similar to those of the wet tropics, the temperatures at elevations of 1500 m and higher are generally lower. In the wet and dry tropical highlands, mean annual temperatures are about 18°C, with the warmest months averaging only about 21°C.

Agroecology and Cassava Bacterial Blight

The short- and long-term economic importance of cassava bacterial blight (CBB), especially with regard to crop losses and epidemic potential, is significantly influenced by seasonal climatic fluctuations, level of susceptibility of favoured cassava cultivars, and the source of *Xanthomonas manihotis* inoculum (Terry 1977). The most important phase of the CBB epidemic results from the planting of infected cassava stakes. The secondary phase of the disease results from lateral dissemination of *X. manihotis* cells from diseased plants.

Cassava bacterial blight is more widespread and severe in the savanna and forest–savanna transition ecological zones of Africa than in the deep rain forest. This has been confirmed in survey reports from Cameroon (Persley 1977), Zaire (Hahn and Williams 1973), Republic of Congo (Daniel et al. 1978), Nigeria (Persley 1978), Tanzania (Nyango 1978), and Uganda (Nyiira and Otim-Nape 1978).

Severe incidences of the disease have, however, been reported from the rain forest zones in Nigeria (Williams et al. 1973) and Cameroon (Persley 1977). Sporadic outbreaks of the disease have also been reported in isolated pockets in Togo (Olympio 1978) and Ghana (Korang-Amoakoh and Oduro 1978), and in the latter, although the disease was reported as almost at an epidemic level in 1975–76, its incidence was recorded as almost nil in 1977 in the greater Accra area.

Data from CBB trials conducted in the tropical rain forest region of Nigeria have indicated that the CBB epidemic does not become fully established in this climatic zone (Persley 1978). When first introduced, the disease was severe in susceptible cultivars and generally mild in resistant ones. Also, mortality was high among the susceptible cultivars, especially during periods of heavy rainfall.

The heavy rainfall and almost nonexistent dry season in the tropical wet climatic zones do not provide favourable conditions for the survival of *X. manihotis*. Therefore, although the disease develops under these conditions, especially when infected planting material is utilized to establish a crop, the poor survival of *X. manihotis* in soil and debris reduces the inoculum for the succeeding crop. The subsequent use of CBB-free planting material can break the disease cycle and reduce the epidemic potential.

Data from CBB trials conducted in the forest–savanna transition zone of the wet and dry tropics in Nigeria have indicated that with adequate rainfall (Mokwa and Ibadan 1100 mm and 1270 mm, respectively), severe CBB develops in sus-

ceptible cultivars. Where there is a long dry season (5–7 months), the conditions are quite favourable for the survival of *X. manihotis* (Persley 1978), and a sustained CBB epidemic occurs (Table 2).

STRATEGIES FOR FUTURE RESEARCH

The ultimate goal of cassava improvement in Africa is to develop varieties with high yield, disease and pest resistance, and adaptability to a wide range of climatic, soil, and cultural characteristics. To achieve this goal, researchers must identify genotypes with moderate or high tolerance or resistance to a combination of the stress factors that affect the productivity of the crop under various ecological conditions.

Takatsu et al. (1978) have demonstrated, through growth-chambre studies in Brazil, that, when temperature does not fall below 22°C at night and 30°C during the day, susceptible cassava cultivars normally develop only mild CBB and generally recover from the disease. However, at lower temperatures both susceptible and resistant cultivars become severely diseased. Furthermore, although plants of resistant cultivars may survive the disease, susceptible plants usually die from it.

Based on these findings, one may presume that, along with the well-documented effect of rainfall on the spread of *X. manihotis* and the severity of CBB (Lozano 1975), temperature plays an indirect role in CBB disease expression in relation to its effect on the growth of the cassava plant.

The African cassava belt is characterized by a great diversity of climatic and edaphic conditions even within the broadly defined wet tropical and wet and dry tropical zones. Temperature and rainfall variations as already indicated result from variations in elevations, ocean currents, prevailing winds, and distances from the equator. Typical examples of such diversity within a given climatic zone are the hill slopes of the Cameroon Peak (4062 m) where mean annual rainfall is often more than 10 000 mm and the mean annual temperature is 26.6°C and the highlands of Kenya where mean annual rainfall is about 1000 mm, but where in the Rift valley, with local variations due to relief, the precipitation is about 750 mm and on the exposed slopes of Mount Kenya where it is invariably more than 1500 mm (Hailey 1957).

In the tropical humid climatic zones of Africa, the constantly high temperatures and abundant annual rainfall lead to intense chemical weathering of soils. This results in a complete or nearly complete decomposition of minerals and removal of soluble silica and bases (Brook 1979). The soils are, therefore, for the most part chemically poor, although in the tropical wet zones the soils generally have good physical structures. In contrast in the tropical wet and dry zones, depending on the length of the dry season, the soils become highly leached and are generally of low fertility (Brook 1979).

The differences in the climatic and edaphic conditions inevitably result in variations in relative humidities, minimum and maximum temperatures, soil pH, soil texture, organic matter content, and macro- and micronutrient deficiencies within and between the main cassava-growing areas in Africa. These, in turn, exert significant effects on the growth of the crop and modify its reaction to its major pathogens. Furthermore, as is shown by the

Table 2. Epidemic potential for cassava bacterial blight in the tropical zones of Africa.

Zones	Latitude	Precipitation (mm)	Seasons	Mean annual temp (°C)	Location	Epidemic potential[a]
Tropical wet	0.5° N/S					
Equatorial	0.32° N			25–27	Kisangani, Zaire	–
Monsoonal	4° N	3000	Year round			
Tropical wet and dry	5–10 ° N/S	3000	10 months wet; 2 months dry	25–27	Douala, Cameroon	+–
Lowland	15–25° N/S	1000–1500	9 months wet; 3 months dry		Timbo, Guinea	+
Highland			6 months wet; 6 months dry	23–26 18–21	Salisbury, Zimbabwe	+

[a]Adapted from Brook, R.H. (1979) and Best, Alan and deBlij, H.J. (1977).

example of CBB in Africa, climatic and edaphic variations also strongly influence the behaviour of the pathogens, in this instance, that of the survival of *X. manihotis*.

It is proposed, therefore, that the research strategies for progress in cassava pathology focus on the identification of factors limiting cassava productivity with special reference to effect of agroecological factors on cassava growth, effect of agroecological factors on the aggressiveness of cassava pathogens, and effect of agroecological factors on the survival and epidemic potential of cassava pathogens.

At the International Institute of Tropical Agriculture (IITA), breeding of improved cassava involves massive crossing and selection primarily against two major diseases — cassava bacterial blight and cassava mosaic disease (CMD). At present, instead of finalization of clone superiority and dissemination from the Ibadan centre, improved true seeds with variable characteristics from different interpollinated females containing sources of resistance and other desired agronomic traits are introduced to locations in different African countries for selection in local environments. In these locations, superior plants are allowed to interpollinate again and some of the seeds collected are returned to Ibadan where they are grown and reselected.

This system ensures the progressive improvement of the varieties toward adaptation to the disease and other stresses in the many local ecologies. The timespan, however, from the acquisition of the source populations, with genes associated with desirable characters, to the selection of elite clones and their multiplication for distribution to farmers is about 6 years. Many African national cassava programs, because of a serious lack of personnel to establish such a lengthy crop-improvement program and the immediate need for plants with high tolerance to the major diseases, urgently require alternative procedures.

Hitherto, phytosanitary regulations have prohibited the movement of vegetative cassava planting material within the African continent because of the threat of accidental introduction of vegetatively borne pathogens and pests into areas presumed free of these agents. With the recent development of techniques for the production of pathogen-free cassava planting material in tissue culture, the possibility now exists for improved cassava varieties that have been tested in Nigeria under a range of environmental conditions and various levels of disease stress to be introduced into national programs.

The improved IITA-bred varieties proposed for distribution are TMS 30555, TMS 30572, TMS 30786, TMS 30557, TMS 30001, and TMS 30395; they have proved superior in yield and performance in the majority of the environments in which they have been evaluated. Two of these improved varieties, TMS 30555 and TMS 30572, have produced average yields of 40.8 and 36.0 t/ha in 12 months, and the latter had a yield of 68 t/ha in 15 months in Ibadan, Nigeria, on soils where cassava had been consecutively planted for 2 years without fertilizer application (IITA 1979).

The improved varieties are relatively low in cyanide content, have good root shape, and good resistance levels to CBB and CMD. Their quality is rated excellent for consumer acceptance, and their percentage dry matter is relatively high (32% and 36% at 12 and 15 months after planting respectively).

The Inter-African Phytosanitary Council (IAPSC) has reviewed the proposal for the movement of these improved varieties in tissue culture from IITA to African countries whose national programs request them. The indications are that subject to recommendations from the Plant Quarantine Services (PQS), Moor Plantation, Ibadan, the IAPSC will endorse the issue of the Phytosanitary Certificates to legalize the movement of these varieties within Africa.

The short- and long-term benefits from the introduction of improved cassava varieties in tissue culture to national cassava programs include the immediate availability of clonal material for uniform varietal evaluation within a national program, the identification of varieties adapted to local ecologies within 1 or 2 growing seasons, and the possibilities for replacing unimproved low-yielding, disease-susceptible varieties with improved high-yielding varieties adaptable and tolerant to the local ecological stresses. National programs will nevertheless continue to introduce new genotypes as true seed for local selection.

With regard to the desired progress in cassava pathology research, the availability of uniform clonal material will provide the possibilities for investigating variations in cassava pathogens due to ecological differences, and the influences of the ecological stresses on the crop's productivity and on the stability of varietal resistances to major cassava pathogens.

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FIELD SCREENING OF CASSAVA CLONES FOR RESISTANCE TO *CERCOSPORA HENNINGSII*

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Field screening of cassava clones for resistance to *Cercospora henningsii* was conducted by artificial inoculation and natural infection during October–November 1977 and June–July 1978, dry and wet seasons, respectively. During both screening seasons, clones K7709, K7713, K7717, and K7718 showed some resistance, whereas clones Isunikakiyan, TMS 711121, TMS 30395, K7707, and K7711 showed susceptibility. *Cercospora* leaf spot, which generally was more severe during the wet season, developed more reliably following artificial inoculation than from natural infection. Although none of the clones proved to be immune, the differences in responses to *C. henningsii* suggest that opportunities exist for breeding clones with brown leaf spot resistance.

La sélection sur le terrain de clônes de manioc pour la résistance à *Cercospora henningsii* a été effectuée par inoculation artificielle et infestation naturelle en octobre et novembre 1977 et en juin et juillet 1978, soit en saison sèche et humide. Pendant la période d'essais, les clônes K7709, K7713, K7717 et K7718 ont démontré une certaine résistance à l'anthracnose alors que Isunikakiyan, TMS 711121, TMS 30395, K7707 et K7711 faisaient plutôt preuve de tolérance. L'inoculation artificielle a, plus que l'infestation naturelle, favorisé le développement de *Cercospora*, généralement plus grave en saison humide. Bien qu'aucun clône n'ait résisté à l'attaque, les différentes réactions à l'anthracnose font envisager la possibilité de sélectionner des variétés en vue de la résistance à cette maladie.

Several *Cercospora* species have been reported to induce leaf spots on cassava (Ciferri 1933; Arene 1974; Lozano and Booth 1974; Maduewesi 1974; Teri et al. 1977; Kasirivu 1978). The severity and geographical distribution of *C. henningsii*, causing brown leaf spots on cassava, indicate that it is the most important species (Van Overeen 1952; Lozano and Booth 1974; Teri et al. 1977).

Recently, at Centro Internacional de Agricultura Tropical (CIAT) weekly spraying of fungicide to control brown leaf spot and leaf blight on a susceptible variety of cassava, Llanera, increased yields by 14% (Teri et al. 1977). Control measures against brown leaf spot alone resulted in an increase in fresh root yield from susceptible cultivars ranging from 10 to 23% (Teri et al. 1977).

Little attention has been paid to the development of control measures, as the disease has never been reported to be lethal; infected plants continue to yield (Ciferri 1933; Viegas 1941; Müller and Roberts 1951). It seems probable that the conditions of traditional cultivation of cassava in small backyard plots with other crops either have restricted the spread of the disease or have concealed epidemics (Lehman 1972). The disease may become important, however, when cassava is grown in intensive monocultures of one variety (Rorer 1915).

Eradication measures, such as frequent raking and burning of fallen cassava leaves during the dry season, cutting back the plants to 15 cm during the dry season and burning the debris, and rotating cassava with other crops have been suggested by Powell (1968). Several fungicides have shown promise for the control of brown leaf spot (Arene 1974; Lozano and Booth 1974; Teri et al. 1977), but fungicidal control of brown leaf spot, although feasible, is uneconomic except where multiplication of disease-free planting material is involved (Arene 1974).

Although other control measures have been attempted, breeding for resistance has received little attention (Powell 1968; Arene 1974; Lozano and Booth 1974). More research in evaluating resistance and its mechanisms is still required. Ciferri (1933) reported on the assessment of resistance to *C. henningsii* of cassava clones based on lesion numbers and distribution. CIAT (1975) and Teri et al. (1974) used the amount of leaf retention to grade disease severity.

Differences in the reaction of cassava clones to *Cercospora* spp. have been demonstrated (Ciferri 1933; CIAT 1974, 1975, 1976; Maduewesi 1974). Screening at CIAT of cassava germ plasm led to the identification of a number of clones with resistance and tolerance to *C. henningsii* (Teri et al. 1977).

Greenhouse screening has been difficult because fungal sporulation in culture is insufficient for artificial inoculation. Recently, however, CIAT (1975) and Kasirivu (1978) have reported satisfactory sporulation of *C. henningsii* in culture, and their technique should facilitate disease evaluation of artificially inoculated plants.

A vital prerequisite of successful breeding for resistance is a reliable screening technique. Our research was undertaken to determine the usefulness of the assessment scale of disease-severity ranking as well as the effect of environmental conditions on disease development on inoculated cassava clones. We hoped to find out how reliable and comparable were the results of artificial inoculation from year to year and how they compared with natural infection.

MATERIALS AND METHODS

The cassava clones used in the screening experiments included Isunikakiyan, 60444, 58308, 711121, TMS 30017 (TMS = tropical manihot), TMS 30211, TMS 30337, TMS 30395, TMS 30555, TMS 30572, and 17 other clones designated K7701 to K7719 (K77 = Kasirivu 77 standing for the clones screened in 1977 by Kasirivu); they were selected from the cassava seedling nursery at IITA. Only 27 clones were used in the field experiments for efficient experimental management and evaluation of the developed scale.

PURE CULTURE AND CRUDE MACERATE AS INOCULUM

Crude macerate and pure culture were used for inoculation. Naturally infected leaves of cassava were collected from IITA cassava fields, and disease lesions cut out with a pair of scissors. Approximately 500 g of the diseased tissue discs were macerated in a blender at low speed in 500 ml of distilled water for 30 seconds and then filtered through cheesecloth. Also, 10 pure culture plates on bean pod agar (BPA), which had been flooded with pure culture preparations and incubated for 14 days, were blended in 300 ml of distilled water and sieved through cheesecloth.

The inoculum suspensions were adjusted at 50 000 spores/ml, unless otherwise stated, by use of a hemocytometer (Kasirivu 1978). Tween 80 (a sticker) was added at a rate of one drop for every 100 ml to reduce runoff of the inoculum suspension on the treated foliage. The foliage of the plants was sprayed to the runoff point with the inoculum suspension. To assess the differences in crude macerate and pure inoculum, we used 8–10-week-old potted plants of Isunikakiyan cultivar raised in the greenhouse, inoculating them with either crude macerate or pure culture suspension (25 000 spores/ml). Treated plants were maintained in a humidity chambre (90–100% relative humidity) for 48 hours and then transferred to the greenhouse bench. Four plants were used per treatment and replicated three times. The assessment was carried out in terms of incubation period.

EFFECTS OF HUMIDITY

Isunikakiyan, 60444, 58308, and TMS 30211 cassava clones raised in the greenhouse to age 8–10 weeks were inoculated with the crude macerate and given one of four treatments after inoculation:

- Some plants were maintained outside throughout the assessment where the monthly average temperature ranges were 20.4–31.9°C for November–December 1977 and 22.9–31°C for April–May 1978;
- Some plants were maintained on a greenhouse bench throughout the observation period;
- Some plants were transferred to a humidity chambre for 48 hours at 90–100% relative humidity (RH) and then transferred outside where they were maintained throughout the observation period; and
- The remainder were placed in a humidity chambre (90–100% RH) for 48 hours and then transferred to the greenhouse bench for the rest of the observation period.

The experiment was replicated twice. The assessment method was to determine the incubation period of the disease and leaf spot count per plant at 15-day intervals from the 30th to the 60th day after inoculation.

EFFECT OF MOISTURE STRESS

Potted plants of Isunikakiyan cultivar raised in a greenhouse to age 8–10 weeks were inoculated with the crude macerate and subjected to one of four watering regimens:

- Watered daily (control);
- Watered every other day;
- Watered once every 3 days; and
- Watered once every 4 days throughout the observation period.

The treatment results are presented in terms of incubation period of the disease.

HOST VARIETAL RESPONSE

Potted plants of clones Isunikakiyan, 60444, 58308, and TMS 30211 raised in the greenhouse to age 8–10 weeks were artificially inoculated with

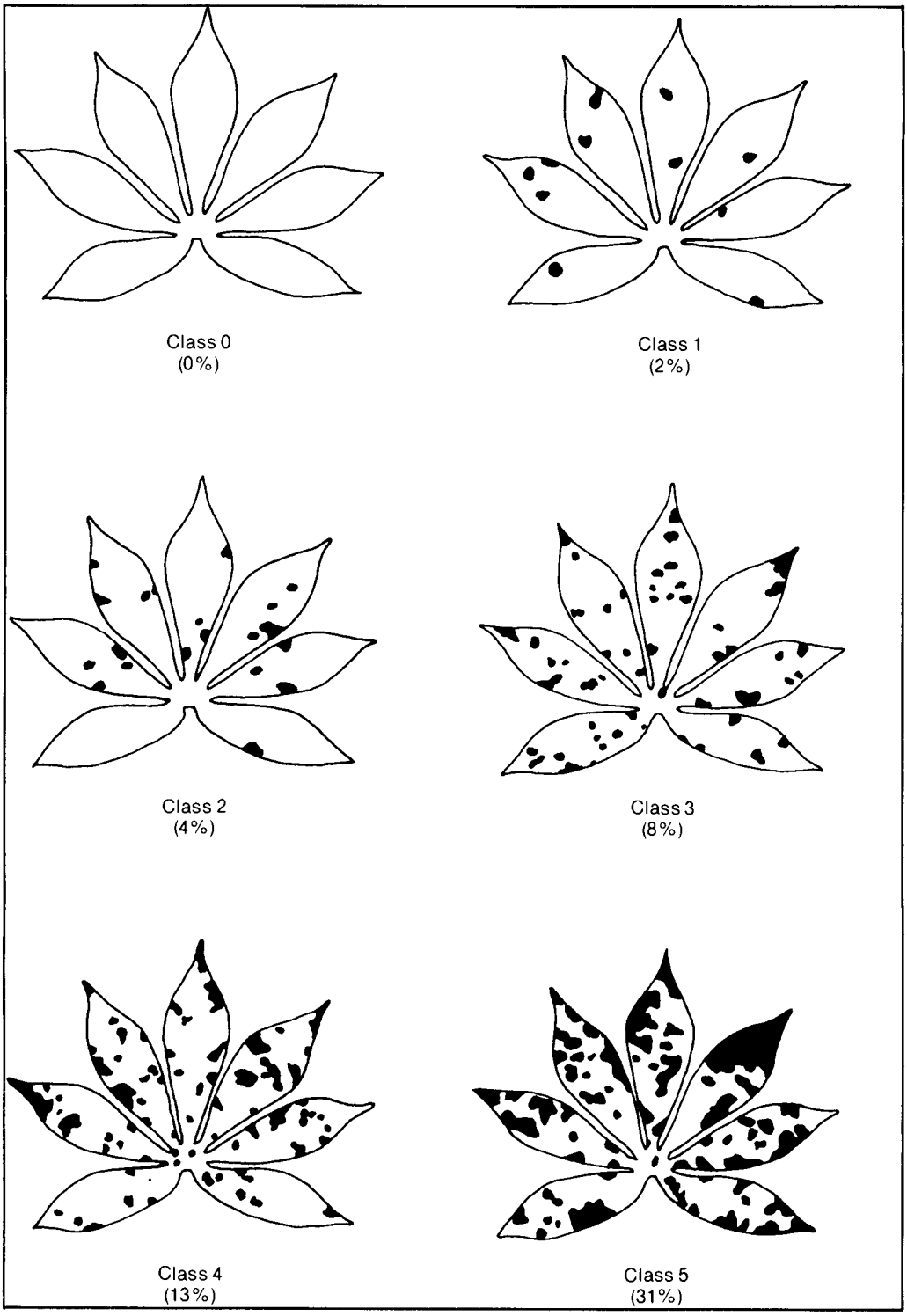

Fig. 1. *A standard scale for brown leaf spot disease rating with percentage of diseased leaf.*

crude macerate and maintained outside throughout the observation period. Plants sprayed with distilled water were used as controls. The observations included leaf spot count per plant and the amount of defoliation at 30, 45, and 60 days after treatment.

PLANTING, CULTURAL PRACTICES, AND INOCULATION

Six stems of each of the 27 clones were planted a metre apart on ridges also a metre apart. There were 27 rows in a block (replicate), and 3 metres between each block. Two replicates were established for each screening experiment. The weeding and irrigation were carried out when necessary. The experiment established during the dry season (February 1978) was sprayed twice with Gammalin 20 at weekly intervals to protect the plants from the variegated grasshopper, *Zonocerus variegatus*.

The foliage of the test plants was inoculated when the plants were 3 months old. Inoculation was done in the evening. Two of the four blocks received the inoculation treatment, and the other two were uninoculated controls.

STANDARD DISEASE ASSESSMENT SCALE

Equal-sized mature leaves representing all possible levels of infection were collected from the field, taken to the laboratory, and categorized into six arbitrary classes of disease severity based on lesion numbers and proportion of leaf areas diseased. The representative leaves of each class were selected and traced on translucent paper for an assessment scale (Fig.1). The leaf area affected by the disease was assessed by square counting. Resistance–susceptibility grading of screened clones was on a scale of 0–5: immune (0), highly resistant (1), resistant (2), moderately susceptible (3), susceptible (4), and highly susceptible (5).

The disease severity of both inoculated and uninoculated treatments was assessed at 30, 45, and 60 days after inoculation (Kasirivu 1977, 1978). A mean reaction score was calculated for each clone. An assessment scale based on percentage of diseased leaf area was used for evaluation by a quantifying scale (Thurston 1971; van der Plank 1976). Personnel rated disease by looking at the lowest quarter of the test plant's foliage and assigning a score according to the most severely diseased leaf of those examined on the inner four plants in each row.

RESULTS

CRUDE MACERATE VERSUS PURE CULTURE INOCULUM

Crude macerate and pure culture suspensions produced similar disease symptoms on treated plants; the incubation ranged from 20 to 23 days for crude macerate and 20 to 25 days for pure culture. Fungi were isolated from the infected plants of both treatments, and the cultures were identical with those of the original isolates.

HUMIDITY AND DISEASE DEVELOPMENT

Although the second aim was to find out the role of humidity in disease establishment and subsequent progress, varietal response to the humidity treatments was observed also. Isunikakiyan, 60444, and TMS 30211 transferred to the greenhouse bench immediately after inoculation showed a delay in symptom appearance and no disease symptoms developed on clone 58308 in either experiment. Inoculated plants maintained under high humidity and then on the greenhouse bench showed a delay in symptom appearance on

Table 1. Clonal response to inoculation with *C. henningsii* followed by different humidity treatments. Data expressed as leaf spots per plant 45 days after inoculation. Incubation period (days) is given in parentheses.

Treatment soon after inoculation	Experiment[a]	Isunikakiyan (1)	Isunikakiyan (2)	60444 (1)	60444 (2)	TMS 30211 (1)	TMS 30211 (2)	58308 (1)	58308 (2)
Maintained outside		45.75 (22)	24.34 (19)	48.25 (21)	31.67 (23)	35.00 (23)	25.50 (19)	3.75 (40)	18.50 (27)
Maintained on greenhouse bench		3.50 (24)	4.00 (32)	— [b]	2.50 (41)	—	0.50 (32)	—	—
Maintained under high humidity; then outside		39.33 (23)	42.75 (21)	34.75 (23)	54.65 (19)	5.50 (26)	65.75 (19)	2.50 (32)	9.75 (29)
Maintained under high humidity; then greenhouse bench		8.25 (24)	53.75 (22)	2.00 (31)	2.50 (31)	1.75 (35)	4.50 (23)	—	1.00 (31)

[a]Experiment (1) November–December 1977; experiment (2) April–May 1978.
[b]A dash indicates no disease symptom development.

Table 2. Moisture stress and brown leaf spot disease establishment on Isunikakiyan cultivar, expressed as incubation period (days).

Watering treatment	Exp. 1	Exp. 2
Once a day	21	29
Every 2 days	26	34
Every 3 days	30	30
Every 4 days	52	35

all clones in both experiments. Lowest disease severity was observed on plants inoculated and maintained on the greenhouse bench. The highest disease level on all clones was observed on plants inoculated and maintained outside in the first experiment (November–December 1977), although in the second experiment (April–May 1978) the clones exhibited different responses (Table 1).

MOISTURE STRESS

The appearance of disease symptoms was delayed as the frequency of watering was reduced. The brown leaf spots were observed first on plants watered everyday and last on plants watered once in 4 days (Table 2).

VARIETAL RESPONSE

The lesion numbers on inoculated plants were highest on Isunikakiyan clone and lowest on 58308 clone, with clones 60444 and TMS 30211 exhibiting intermediate reactions at 30 and 45 days after inoculation. After symptom appearance, disease progress on clones Isunikakiyan, 60444, and TMS 30211 was rapid between the 30th and 45th day after inoculation; the disease level decreased rapidly between the 45th and 60th day to almost the same level as the control treatment. Clone 58308 exhibited the least reaction and its lesions per plant were still increasing at the end of the assessment (Table 3).

The defoliation of both inoculated and uninoculated controls was assessed. The clones of Isunikakiyan, 60444, and TMS 30211 that exhibited a high number of lesions and then a sudden decrease showed 80–97% loss of inoculated leaves. Clone 58308 showed a defoliation of about 59% of the inoculated leaves. Defoliation due to the disease was determined by subtraction of the defoliation on control plants. At 45 days after inoculation, defoliation was highest on clone 60444 and least on clone 58308; the other clones were intermediate; and, at 60 days after treatment, clones 60444 and TMS 30211 showed the highest defoliation, clone 58308 the least, and clone Isunikakiyan remained intermediate (Table 4).

FIELD SCREENING FOR RESISTANCE

A third aim was to identify the resistant and susceptible clones to artificial inoculation and natural infection during both dry and wet seasons. In the 27 clones screened, no immunity was observed; all clones became infected even without inoculation. Inoculated clones during both seasons showed a higher disease level than the uninoculated controls except for clones TMS 30337 and TMS 30017, which had the same disease severity score on both treatments during the dry-season screening, as did clone K7717 during the wet-season screening.

During the dry-season screening (October–November 1977), only four clones (TMS 30211, K7701, K7704, K7709) exhibited high resistance, and only one (K7717) showed high resistance during the wet season (June–July 1978). Nine clones were resistant in the dry season, and four clones were resistant in the wet season, two of which (K7713, K7718) exhibited the same level of resistance in both seasons. Fourteen and 15 clones were rated moderately susceptible during the dry

Table 3. Leaf spot number per plant on inoculated and uninoculated cassava clones.

Clone	Treatment	Days after treatment		
		30	45	60
Isunikakiyan	Inoculated	68.50	221.75	25.25
	Control	6.75	23.00	21.25
TMS 30211	Inoculated	11.00	83.00	24.50
	Control	0.50	0.50	10.25
58308	Inoculated	1.33	26.33	36.00
	Control	1.00	3.00	2.00
60444	Inoculated	27.25	77.25	22.50
	Control	1.75	10.00	17.00

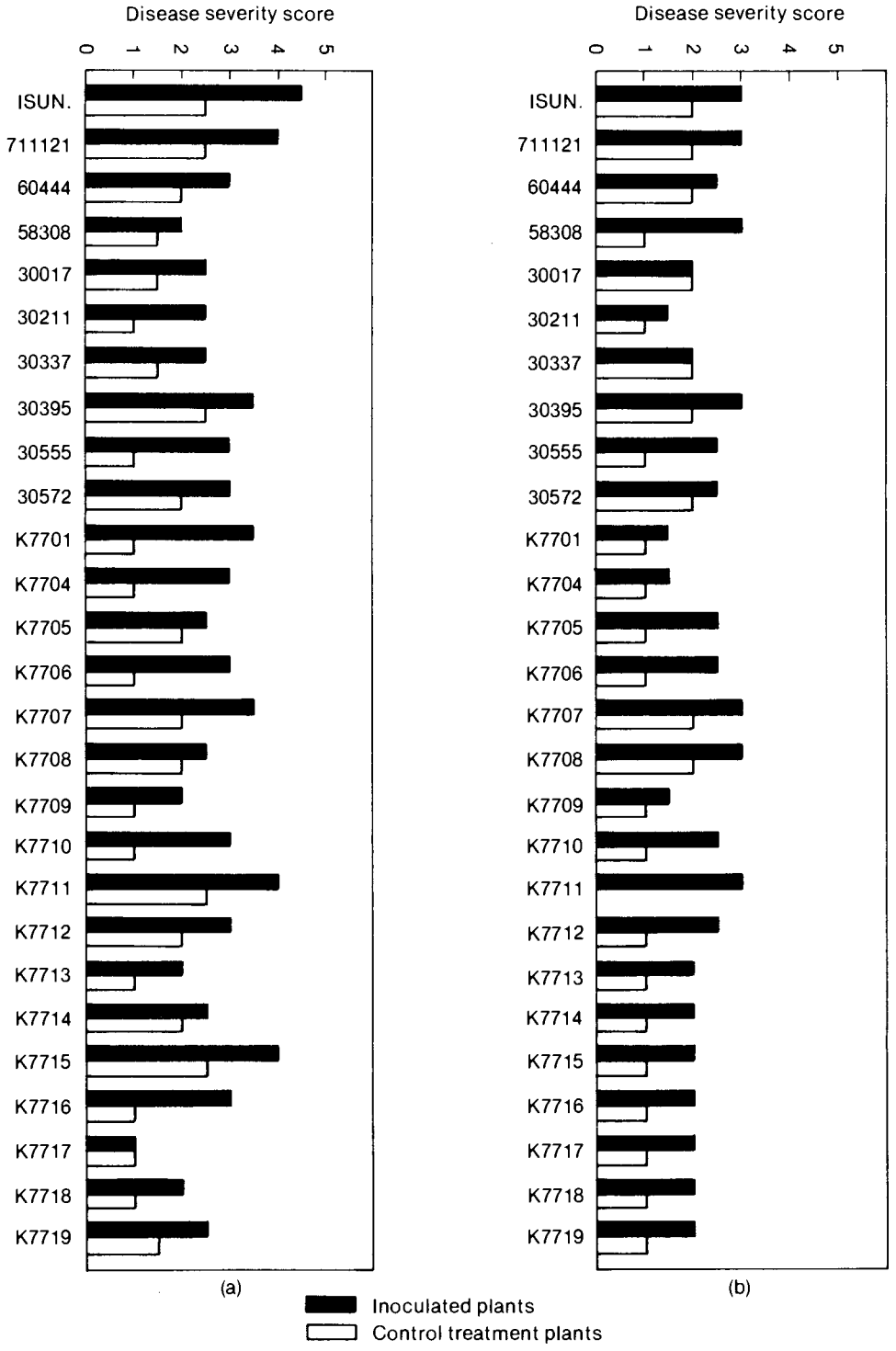

Fig. 2. *Cassava brown leaf spot disease severity score 30 days after treatment on 27 clones during the wet (a) and dry (b) seasons.*

Table 4. Defoliation percentage caused by brown leaf spots on four cassava clones.

Clone	Days after treatment		
	30	45	60
Isunikakiyan	7.50	24.32	35.69
TMS 30211	2.99	26.44	42.12
58308	7.58	13.51	20.83
60444	0.43	35.97	42.12

and wet seasons, respectively, and 8 of these (60444, TMS 30555, TMS 30572, K7705, K7706, K7708, K7710, K7712) exhibited the same disease score in both seasons. In the wet season, clones 711121, TMS 30395, K7701, K7707, K7711, and K7715 were graded susceptible, and Isunikakiyan clone, highly susceptible.

The inoculated treatments showed various clonal responses that followed a pattern similar to that of the control treatments except that the disease severity scores of the former were higher (Fig. 2).

The subsequent disease assessment of inoculated plants at 45 and 60 days after inoculation showed clonal response to the disease severity in the field (Table 5). Clone TMS 30395 maintained a moderately susceptible reaction throughout the assessment in the dry season, and clone TMS 30572 maintained a similar response during the wet season. Clones 58308 and K7718 were resistant, and clone K7717 had a highly resistant reaction during the wet season. Only clone K7708 showed a delayed disease development, its highest score for the wet season being observed 45 days after inoculation. Clonal response was most meaningful at 30 days after inoculation before second-generation lesions appeared on the treatments and before defoliation due to disease set in.

DISCUSSION AND CONCLUSIONS

The inoculation results showed that the disease organisms in pure culture and crude macerate are

Table 5. Brown leaf spot disease progress given as disease assessment score after 30, 45, and 60 days on inoculated cassava clones during the dry (October–November 1977) and wet seasons (June–July 1968).

Clone	Dry season			Wet season		
	30	45	60	30	45	60
Isunikakiyan[ab]	3	2	2	4.5	3	3
711121[a]	3	1.5	1.5	4	3	3
60444	2.5	1.5	1.5	3	2.5	1.5
58308	3	2.5	2.0	2	2	2
TMS 30017	2	1.5	1.5	2.5	2.5	2
TMS 30211	1.5	1.5	1	2.5	2	2
TMS 30337	2	1.5	1	2.5	2.5	2.5
TMS 30395[b]	3	3	3	3.5	2	2
TMS 30555[b]	2.5	2	1.5	3	2.5	1.5
TMS 30572	2.5	2	2	3	3	3
K7701	1.5	1	1	3.5	2.5	2
K7704	1.5	1	1	3	2	1.5
K7705[a]	2.5	1	1	2.5	2	1
K7706	2.5	1.5	1	3	2.5	2
K7707	3	2	2	3.5	2.5	2.5
K7708	3	2.5	1.5	2.5	3	2.5
K7709	1.5	1	1	2	1.5	1
K7710	2.5	1.5	1	3	2	1.5
K7711[ab]	3	1	1	4	3	3
K7712	2.5	1	1	3	2	2
K7713	2	1	1	2	2	1.5
K7714	2	1.5	1.5	2.5	2.5	2
K7715	2	1.5	1	4	3	3
K7716[b]	2	2	1	3	2.5	2
K7717	2	2	1	1	1	1
K7718	2	2	1.5	2	2	2
K7719	2	1	1	2.5	2.5	2

[a]High cassava mosaic disease level during dry season.
[b]Severe premature yellowing of leaves during wet season.

equally virulent on the tested clone, Isunikakiyan, although the spectrum of virulence of the pure culture was not tested.

The progress of infection was highly dependent on the environmental conditions to which the clones were exposed soon after inoculation and partially dependent on the clone. Clonal responses to humidity treatments are reflected in the length of incubation and lesion numbers. Drier environmental conditions in the greenhouse delayed or even circumvented symptom appearance, whereas natural conditions and graded humidity treatments induced the inherent response of the clones to the disease.

The high number of lesions on plants maintained outside indicates that there are many factors other than humidity involved in the process of infection, and these factors may include alternating high and low levels of relative humidity during the night and day, fluctuating temperature, and a combination of high humidity and low temperature at night.

Plants inoculated and maintained outside developed more lesions per plant than did plants maintained under high humidity during November–December 1977. The explanation is that the humidity chambre reached temperatures as high as 38–40°C and reduced the number of successful infections, whereas, outside, the temperature was 20–32°C. The April–May 1978 experiment showed fewer lesions per plant on the plants inoculated and maintained outside than on plants inoculated and maintained under high humidity before being transferred outside. Perhaps the spores on the leaves outside were washed away by the rain.

The moisture stress experiment showed that vigorously growing plants with adequate moisture exhibit a high disease level by both short incubation and great numbers of lesions evenly distributed on the leaves. Inoculated leaves of plants subjected to moisture stress had delayed appearance of symptoms and fewer leaf spots.

The differences in clonal response to artificial inoculation may be attributable to the differences in the rate of infection following inoculation and to differences in resistance of invaded leaf tissues, which affected the rate at which infected leaves were destroyed (Thurston 1971; van der Plank 1963). As the test plants were artificially inoculated, other factors besides amount of inoculum per unit leaf area may have played a part.

Both inoculated and uninoculated controls of clone Isunikakiyan showed a high disease level, whereas both treatments of clone 58308 developed very few spots. Clones 60444 and TMS 30211 showed intermediate reactions. The peak reaction in terms of lesions per plant of clones Isunikakiyan, TMS 30211, and 60444 was observed at 45 days after inoculation, whereas clone 58308 showed a low lesion number and a low, steady increase of lesions per plant up to the end of the observation. Under the same disease pressure, i.e., inoculation, clone Isunikakiyan had about nine times — and clones 60444 and TMS 30211 had about three times — the number of lesions that clone 58308 had on the 45th day. The untreated control plants showed a similar response except for clone TMS 30211, which showed a more resistant reaction at lower disease pressure.

Of the four clones investigated, 60444 and TMS 30211 had the highest defoliation 60 days after inoculation, and clone 58308 had the least; clone Isunikakiyan had intermediate defoliation. When we compared disease severity with the defoliation due to disease, we observed that clones 60444 and TMS 30211 had the highest defoliation, although their disease severity was intermediate; in contrast, Isunikakiyan showed intermediate defoliation and the highest disease level. These findings suggest that clones 60444 and TMS 30211 have a more sensitive reaction to the disease.

In summary, clone Isunikakiyan showed susceptible reactions; clone 58308 resistant reactions; and clones 60444 and TMS 30211 intermediate reactions. The term susceptible denotes the total of qualities that make a plant a fit host for a pathogen, whereas resistant denotes the basic ability of the host to hinder the pathogen (Robinson 1969).

The field screening for resistance of 27 cassava clones was carried out twice during the dry season (October–November 1977) and the wet season (June–July 1978). The clonal response of both inoculated and uninoculated controls during both seasons exhibited the various disease levels, and disease levels were higher during the wet season than during the dry season. The responses agree with what was observed by Viennot Bourgin and Grimaldi (1950): cassava plants subjected to adverse growing conditions are more resistant to *Cercospora* sp. than those under favourable conditions. Whether the results indicate mere resistance or just lower disease scores is not clear. The results may indicate a pathogen–host–environment effect rather than a host–environment effect because humidity, moisture stress, and clonal differences affected disease level on artificially inoculated plants under controlled environmental conditions.

Of field-inoculated plants, 78% of the clones exhibited high disease scores during the wet season when compared with their levels during the dry season; 11% of the clones showed lower disease

scores during the wet season; and another 11% of the clones exhibited equal responses during the two seasons. These same clones when used as inoculated controls had different levels of disease: 33% showed higher disease levels during the wet season, 7% lower disease levels during the same season, and 60% an equal response during both seasons. Such clonal interaction with season and inoculum potential in these experiments confirms what Teri et al. (1977) pointed out that generally artificial infections are more reliable from year to year than natural infections and, therefore, more comparable.

The clonal responses of inoculated plants showed more or less a normal distribution during the wet season, whereas during the dry season the response was skewed from middle severity toward resistant. On the uninoculated controls, clonal response was skewed toward the resistant side of the assessment scale in both seasons with the exception of a few clones that exhibited moderate susceptibility during the wet season. Effective screening requires artificial inoculation during the wet season when the weather favours vigorous plant growth and is conducive to disease development. This approach would give reliable and more comparable results from year to year.

The differences in clonal responses to *C. henningsii* have been demonstrated in the experiments carried out, and these observations are similar to those of Arene (1974), CIAT (1974, 1975, 1976, 1977), and Maduewesi (1974). One may assume that there exists resistance at all possible levels in the cassava clones tested but no immunity. However, more greenhouse and field screening for resistance is needed to confirm the findings and the accuracy of the disease assessment scale.

PROPERTIES OF A SEVERE STRAIN OF CASSAVA LATENT VIRUS ISOLATED FROM FIELD-GROWN TOBACCO IN NIGERIA

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I isolated and tested the agent causing severe stunting, leaf curl, leaf epinasty, and chlorosis mottle in field-grown tobacco in Nsukka, Nigeria. The agent was shown to be a virus, isolates of which were able to infect *Datura stramonium* and several *Nicotiana* species. The virus exhibited thermal inactivation at 55–60°C, dilution endpoint of less than 10^{-1}, longevity in vitro of fewer than 24 hours, and a spherical morphology. It was transmitted by *Bemesia tabaci*. Based on these properties, I consider the virus to be a severe strain of cassava latent virus (CLV), although results of studies on agar to demonstrate the possible serological relationship between the Nsukka virus and CLV were inconclusive.

L'agent responsable du rabougrissement sévère, de la frisolée, de l'épinastie et de la marbrure chlorotique du tabac cultivé à Nsukka, Nigeria a pu être isolé et étudié. C'est un virus et plusieurs isolats ont été injectés à *Datura stramonium* et à d'autres espèces *Nicotiana*. Le virus, de morphologie sphérique, est inactif à 55–60 °C ainsi que lorsque dilué à moins de 10^{-1}, et il ne vit pas plus de 24 heures en laboratoire. Il est transmis par *Bemesia tabaci* et attendu les caractères décrits plus haut, il est possible qu'il appartienne à une variété du virus latent du manioc (VLM), bien que des recherches sur l'agar n'aient démontré aucune relation sérologique entre VLM et Nsukka.

Cassava latent virus (CLV) is relatively new, having been described in Kenya in 1978 by Bock et al. (1978). CLV is sap-transmissible and is inactive at temperatures higher than about 55°C. Its dilution endpoint is about 10^{-3}; longevity in vitro about 3 days; it infects Euphorbiaceae and Solanaceae in which it causes leaf curl, chlorotic lesions, and chlorotic vein banding (Bock et al. 1978).

There is new interest in CLV because it has consistently been isolated from cassava showing symptoms of cassava mosaic disease (CMD) (Bock et al. 1978; Igwegbe, unpublished results; Thottappilly, personal communication, and Cobaruko, unpublished thesis). CMD is a serious disease of cassava wherever the crop is grown. Although CLV has been transmitted experimentally from cassava to tobacco, the virus has never been observed in nature on tobacco.

In a 1979 survey of viruses infecting tobacco at the University of Nigeria tobacco plot at Nsukka, Nigeria, severely stunted plants with symptoms of leaf curl, leaf epinasty, and chlorotic mottle were found. Studies done to determine the causal agent of this disease showed that it was caused by a strain of CLV.

MATERIALS AND METHODS

Of 10 virus isolates (6 from field-grown tobacco and 4 from CMD-infected cassava kept in the greenhouse) obtained in Nsukka, one designated CLV-NN2 was used in my study. CLV-NN2 isolate was from field-grown tobacco. After several serial local lesion passages in *Nicotiana occidentalis*, CLV-NN2 was maintained in *N. tabacum*, NC 95 or a local cultivar. Unless otherwise indicated, these two varieties served as virus sources in this study.

I obtained the inoculum for a host-range study by grinding, in a mortar and pestle, infected tobacco leaves, with 0.05 M potassium phosphate buffer, pH 8.0 (1 : 2, V/V). The brei was passed through two layers of cheesecloth before the inoculum was applied to carborundum-dusted leaves of test plants. The inoculum was washed from the leaves with tap water immediately after application. Inoculated plants and appropriate uninoculated controls were moved to an insect-controlled greenhouse for observation.

Four or more young, rapidly growing, plants of each species were inoculated. If no symptoms resulted on reported hosts after 4–6 weeks, inoculations were made from uninoculated leaves to local or NC 95 variety of *N. tabacum*.

CLV-NN2 was partially purified from NC 95 tobacco leaves harvested about 4 weeks after inoculation. Twenty grams of freshly harvested infected leaves were ground in an ice-cold mortar

and pestle in the presence of 40 ml of 0.1 M potassium phosphate buffer (pH 7.0) containing 1% 2-mercaptoethanol. The homogenate was filtered through two layers of cheesecloth, and then the filtrate was clarified by use of n-butanol–chloroform mixture (1 : 1, V/V), which was used at the rate of 1 ml/10 ml of extract. The mixture was stirred intermittently for 2 hours at 4°C before the emulsion was centrifuged at 3000 rpm for 30 minutes. To precipitate the virus, I dissolved polyethylene-glycol and NaCl in the aqueous phase to final concentrations of 7.5% and 0.4 M, respectively. The mixture was incubated with intermittent stirring for about 2½ hours at 4°C, and the precipitate was collected by centrifugation at 10000 rpm for 20 minutes at 4°C. The precipitate was resuspended in 5 ml of 0.05 M potassium phosphate buffer (pH 8.0) and then clarified by low-speed centrifugation. This final supernatant is referred to as partially purified virus preparation. To test the pathogenicity of the partially purified virus preparation, I inoculated four or more young, actively growing NC 95 tobacco and cassava seedlings. The control plants received similar extract obtained from uninoculated tobacco.

In a study of the particle morphology of CLV-NN2, partially purified virus preparation was negatively stained with 2% neutralized potassium phosphotungstate and then viewed under an electron microscope.

All serological tests were carried out with partially purified virus preparation in Ouchterlony double diffusion plates of 0.8% agarose and 0.1% sodium azide dissolved in saline; 6-mm-diameter wells were spaced 4 mm apart. CLV antiserum employed in this test had a titre of 1 : 256 and was a gift from K.R. Bock of Nairobi, Kenya.

I investigated properties of the crude sap in vitro with expressed juice obtained by titrating infected leaves of a local cultivar of *N. tabacum* in two volumes of 0.05 M potassium phosphate buffer, pH 8.0. Tissues were taken 3–4 weeks after inoculation. All infectivity assays were done on a local cultivar of *N. tabacum*. I determined thermal inactivation point (TIP) by heating 5 ml of the extract for 10 minutes at 10°C intervals from 40 to 80°C. At the end of heat treatment, tubes were immediately cooled and infectivity was determined (five plants/treatment). I determined dilution endpoint (DEP) and again determined infectivity using five plants/dilution. Longevity in vitro (LIV) was determined by incubation of the extract at 21°C. The extract was assayed on five tobacco plants 0–6 days after preparation.

Virus-free adult whiteflies reared on *Crotalaria* spp. were starved for 1 hour and then allowed to feed on infected tobacco for intervals of 30–60 minutes and transferred to test plants for inoculation feeding of 4 days. In another test, viruliferous adult whiteflies collected from CMD-infected cassava kept in the greenhouse were transferred to test plants and allowed to feed undisturbed for 4 days. Whiteflies in both tests were used at the rate of 10/plant and were removed at the end of each inoculation feeding period. Test plants in both tests were tobacco and cassava seedlings in the five- to six-leaf stage. In each test appropriate controls were included.

RESULTS

My results were similar to those of Bock et al. (1978) in showing that the host range of CLV-NN2 was confined to Solanaceous plants (*Nicotiana* spp. and *Datura stramonium*). *Nicotiana* spp. found susceptible that were not investigated by Bock et al. (1978) are *N. tabacum*, Burley 21, Samsun-NN, Havana 425, NC 95, and *N. occidentalis*. With the exception of the last, all the plants developed systemic symptoms. However, local lesions on *N. occidentalis* were erratic and often too few for quantitative assay.

On the other susceptible species, the sequence of symptoms was: 8–10 days after inoculation, crinkles appeared in the leaf base (lower one-half of leaf lamina) of the second, third, or fourth leaf above the youngest inoculated leaf. Within 24 hours, the crinkles became more conspicuous, and chlorotic lesions appeared in the crinkled area. These lesions were usually associated with veins and soon coalesced to form chlorotic vein banding. Within 36–48 hours from the time the first symptoms appeared, the mid-vein portion in the crinkled area became necrotic, especially in *N. tabacum* NC 95, and the local variety. A few hours later, infected plants developed leaf curl followed immediately by severe leaf epinasty. The point of leaf curl usually coincided with the necrotic portion along mid-vein. Temporary cessation of growth and the presence of epinastic leaves gave infected plants a flattened-top appearance. Within 7–10 days after the first reaction, the plant resumed growth.

New leaves lacked epinasty but had a characteristic chlorotic mottle. With time, infected plants became severely stunted compared with uninoculated controls. Sequence of symptom development in *D. stramonium* was similar to that described for tobacco except that in *Datura* the first symptom noted was petiole curl or leaf curl or both. CLV-NN2 in several tests failed to produce necrotic lesions on *D. stramonium*, a finding that supported results of Bock et al. (1978).

Among *Nicotiana* spp., *N. tabacum* NC 95 and the local variety were the most sensitive to inoculation with CLV-NN2, whereas *N. glutinosa* and *N. tabacum* Havana 425 were infected with difficulty. CLV-NN2 in several tests failed to produce symptoms on *D. ferox*, *Solanum nigrum*, and *N. rustica*, which are hosts of CLV.

CLV-NN2 did not incite symptoms in cassava or in any of the following: *Ageratum* spp., *Lycopersicon esculentum* (Marglobe and Roma), *Calapagonium mucoides*, *Crotalaria* spp., *Physalis floridana*, *Capsicum annuum* (California Wonder), *Capsicum frutescens* (Tabasco), *Ipomoea purpurea*, *Gossypium hirsutum*, *Chenopodium amaranticolor*, *Solanum melongena*, *Cucumeropsis* spp., *Urena lobata*, *C. quinoa*, *Ricinis communis*, *Cucumis sativus* (Supermarket and National Pickling), *Vinca rosae*, *Sesamum indicum*, *Datura metel*, *Glycine max* (Lincoln), *Jatropha multifida*, *Pisum sativum* (Bonneville), *Vigna unguiculata* (Blackeye No. 5), and *Hibiscus esculentus*. Except for cassava, none of the above species were assayed for latent virus infection.

Partially purified preparations of CLV-NN2 contained paired particles and some single particles. The paired particles had a total size of 30 × 20 nm, and single particles measured about 18–20 nm in diameter. All tobacco plants inoculated with partially purified virus showed typical symptoms of CLV-NN2 within 2 weeks. None of the tobaccos inoculated with extract obtained from healthy tobacco showed symptoms. None of the inoculated cassava became infected even after three cutbacks within 3 months. Furthermore, I repeatedly failed to recover CLV-NN2 from the inoculated cassava plants.

Partially purified virus preparation of CLV-NN2 did not react with antiserum from Bock in the agar test. The TIP of CLV-NN2 was between 50 and 60°C, the DEP was less than 10^{-1}; and LIV was less than 24 hours.

Virus-free whiteflies failed to transmit CLV-NN2 from infected tobacco to either tobacco or cassava. In contrast, viruliferous whiteflies collected from CMD-infected cassava transmitted CLV-NN2 to tobacco but not to cassava.

DISCUSSION

Host range, symptomatology, and physical properties of CLV-NN2 indicate that the virus is a severe strain of Bock's CLV. Although the host range, symptomatology, and physical properties of CLV-NN2 and CLV are quite close, obvious differences exist. Unlike CLV, my virus failed to infect *S. nigrum*, *N. rustica*, and *D. ferox*; infected *N. glutinosa* and *D. stramonium* only when young infected leaves and buffer were present in a ratio of 1 : 1; caused severe leaf epinasty and chlorotic mottle in susceptible hosts; failed to induce necrotic lesions on *D. stramonium*; and gave slightly lower TIP, LIV, and DEP values than have been recorded for CLV.Because strains of a virus may differ in host range, symptomatology, and physical properties (Bozarth et al. 1977; Fischer and Lockhart 1977; Fribourg 1977), these differences are not inconsistent with the conclusion that CLV and CLV-NN2 are related.

The failure to demonstrate a serological relationship between CLV and CLV-NN2 suggests that the reactants have not occurred in optimal concentrations (Waterworth et al. 1973) or that CLV has serotypes, as is the case with some plant viruses (Harrison 1964; Harrison and Woods 1966). Definitive conclusions regarding a possible serological relationship between CLV and CLV-NN2 must await the results of additional studies, especially the development of improved purification procedures and production of high-titre antiserum.

My failure to return CLV-NN2 to cassava and produce typical CMD symptoms is similar to the experience of Bock et al. (1978). Because the same virus preparation that failed to produce symptoms on cassava caused typical CLV-NN2 symptoms on inoculated tobacco, my inability to infect cassava is unexplained. Even more surprising was my inability to recover CLV-NN2 from inoculated cassava seedlings. These results raise some doubts as to whether CLV is truly latent in cassava. Furthermore, they do not support the view that CLV is the causal agent of CMD.

My attempts to return CLV-NN2 to cassava were hindered in two ways: whiteflies transferred to infected tobacco died within 60 minutes; even when they were allowed to feed for only a very short time, they died soon afterward. Until a more reliable method of returning CLV to cassava is developed, its role, if any, in the etiology of CMD will remain uncertain; however, I suspect the involvement of a complex in the etiology of CMD.

The origin of CLV-NN2 in the field-grown tobacco at Nsukka is not known but is possibly CMD-infected cassava. In the area in which the virus was found, tobacco seedbeds were prepared in close proximity to infected cassava plots. Because this virus has not been isolated from any other hosts in nature, it is quite likely that the tobacco became infected in the seedbeds.

My results show that CLV-NN2 is no longer a mere laboratory curiosity.

CASSAVA BACTERIAL BLIGHT DISEASE IN UGANDA

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The incidence and spread of cassava bacterial blight (CBB) in Uganda is reported. This is the first record of the disease in the country. Blight, wilting, and gum exudations were quite common. West Nile Province had the highest and most serious infection. The year of appearance of the disease and the possibility of the disease having been introduced into Uganda through infected planting materials from Zaire are discussed. The possibility of arthropod transmission of the disease is suggested.

Description de l'apparition et de la propagation de la brûlure bactérienne du manioc en Ouganda. C'est le premier document publié dans ce pays sur cette maladie. La brûlure, le flétrissement, l'exsudation de résine étaient relativement répandus, la province du Nil occidental ayant le taux d'infestation le plus élevé et le plus grave. Il est rapporté que cette maladie a peut-être été introduite par du matériel de plantation infesté provenant du Zaïre. On suggère aussi la possibilité de la transmission de cette maladie par un arthropode.

Cassava is an important root crop in Uganda. It is the main staple in West Nile Province and is widely grown and eaten in Eastern, Northern, and parts of Western provinces of Uganda. In 1974, 2.35 million tonnes of cassava were produced in the country, from 315 000 hectares (Ministry of Agriculture and Forestry 1975).

Until recently, serious diseases of cassava had been few, and these were mainly cassava mosaic and brown streak virus. However, in late 1976, serious leaf spotting, blight, and wilting of cassava incited by *Xanthomonas manihotis* were observed in Nile Province of Uganda. This is the first record of this disease in Uganda, although Hansford (1936) reported a leaf and stem disease of cassava caused by *Bacterium cassavae*. *B. cassavae* is quite different from *X. manihotis*.

Following the confirmation of the disease in Nile and Northern provinces of the country, a detailed survey was undertaken between 29 December 1977 and 31 January 1978. The objectives were to find out the extent of the spread of the disease and the severity of its infection in Uganda so that the affected areas of the country could be demarcated and some phytosanitary measures imposed wherever possible. This paper presents the findings of the survey.

MATERIALS AND METHODS

As far as possible, most parts of the country were surveyed. Two or three districts representing three-quarters of a province were selected. From each of these, a number of subcounties were chosen, so that again three-quarters of a subcounty were covered. Within each subcounty, roads that connect most of the areas were selected and traveled. All cassava fields near the roadside were examined for the presence of cassava bacterial blight. The severity of infection of the individual fields was noted (based on visual estimates of wilted plants, dieback, and leaf blight) on the scale of 0 to 5: where 0 refers to no wilted plants; 1 to very few wilted plants; 2 to few wilted plants; 3 to an average number of wilted plants; 4 to most wilted plants; and 5 to all plants being wilted.

In some cases, a few plants in a field were uprooted and examined for possible effects of the disease on root size and quality. Crop varieties were noted and recorded in local names.

The symptoms of the disease on the plant were also observed and recorded as leaf spots (L), blight (B), and wilt and dieback (W). The number of fields infected and those not infected were counted throughout the survey. From these figures, the percentage of infected fields was calculated as: (total number of fields with infection/total number of fields counted) × 100.

RESULTS

The symptoms caused by this disease have been described by many authors (Lozano and Booth

1974; Lozano and Sequeria 1973; Maraite and Meyer 1975; Terry 1975) and, therefore, will not be covered extensively here. On the leaves, angular leaf spots, which are translucent when viewed through direct light, are very common. These spots coalesce and give the blight symptoms on the leaves. Where conditions are favourable for the disease, destruction of large areas of lamina results. Wilting of leaf lobes or entire leaves, wilting of immature stem tissues, dieback of mature plants, and exudations are quite common.

In our survey, wilting was the most striking symptom, but on entering the infected field, we observed blights and angular leaf spots. Wilting was extensive and also intensive in fields with mature plants, although it was observed in crops less than 6 months old. In a few cases, it was observed that the first shoots to grow from the

Table 1. Incidence and severity of cassava bacterial blight (CBB) in Uganda.

District	County	Subcounty	Crop variety affected	Symptoms[a]	Fields infected (%)	Severity[b]	Remarks
East Lango	Erute	Adeko-kwok	Olepo Gwanda Konyodais	W.L.B.	50	3	
	Erute	Bar	Konyodak	W.B.	52	1	
	Erute	Lira	Olepo	W.B.L.	38	3	
	Moroto	Apala	Okonyodak Olepo, Amici, Acilacil	W.	14	5	Few cassava fields seen; rotting of cassava observed in severely infected fields
	Moroto	Omoro	Okonyodak	W.B.	83	2	
		Abako	Okonyodak	W.B.	67	2	
		Aloi	Okonyodak	W.B.	42	1	
		Amugo	Okonyodak	W.	84	2	
	Dokolo	—	Olepo, Okonyodak	W.B.L.	48	3	
	Otuke	Aduari	Olepo	W.	3	2	Few cassava fields in the area
	Otuke	Orum	—	—	—	—	No cassava fields seen
West Lango	Kele	Akulu	Olepo	W.B.	46	4	
	Kwania	Inomo	Olepo	W.B.	35	3	
	Oyam	Aduku	Olepo Okonyodak	W.B.	18	2	
	Maruzi	Apach	Olepo	W.B.	26	3	
		Cegere	Olepo Okonyodak	W.B.	20	2	
East Acholi	Chua	Labongo	Alepo	W.B.	44	3	Very few fields seen
		Kitgum	Alepo				
		Matidi	Okonyodak	W.B.	44	2	
		Mucwini	Alepo	W.	47	2	
	Lamwo	Madi Opei	Alepo	W.	38	2	
		Padibe	Alepo	B.W.	50	3	
	Aruu	Labongo	Alepo Okonyodak	W.	36	1	Very few fields seen

(Continued)

Table 1. (continued)

District	County	Subcounty	Crop variety affected	Symptoms[a]	Fields infected (%)	Severity[b]	Remarks
West Acholi	Aswa	—	Alepo	W.B.L.	22	1	
	Omoro	—	Alepo Okonyodak Acilacil	B.W.L.	38	2	
	Nwoya	—	Alepo Okonyodak	W.L.B.	56	3	
	Kilak	—	Alepo	B.L.W.	14	1	
South Nile	Padyere	Nebbi	Olepo Okonyodak	W.B.L.	29	2	Leaf spots and blights were very common on young plants
	Okoro	Paidha	Alepo Okonyodak	W.B.L.	30	1	
	Okoro	Nyapea	Tongolo	W.B.L.	48	3	
	Okoro	Attiak	Tongolo Terengule	W.B.L.	58	4	Severe wilting in very young cassava
	Jonam	—	Tongolo Olepo	W.B.L.	51	3	
Central Nile	Ayivu	Aroi	Tongolo Sanja Terengule	W.L.B.	61	5	Most seriously affected
	Terego	—	Tongolo Reregule Sanje Yakobo	W.L.B.	38	3	Localized infection
	Vurra	—	Tongolo Yakobo Sanje	W.L.B.	43	3	
	Madi	—	Olepo Nyarua	W.B.		2	
North Nile	Maracha	Kijumure	Tongolo Sanje	W.B.	57	4	
		Oluvu	Tongolo Sanje	W.B.L.	19	3	Localized infection probably due to planting material and varietal differences
		Nyadri	Tongolo Terengule	W.B.	18	1	
	Ilaboko	Midia	Tongolo	W.B.	14	1	
	Aringa	Kwuru	Tongolo Yakobo	W.B.L.	31	2	
	Aringa	Rumogi	Yakobo Tongolo	W.B.	34	1	

(Continued)

Table 1. (concluded)

District	County	Subcounty	Crop variety affected	Symptoms[a]	Fields infected (%)	Severity[b]	Remarks
Madi	W.Madi	Kura	Andere-ngala				
			Tongolo	W.B.	34		
	W.Madi	Nadu	Tongolo	W.B.L.	23	1	
	W.Madi	Bukele			21	1	
	E.Madi		Olepo				
			Konyodak	B.	16	1	
North Bunyoro	Kibanda	Mutunda	Olepo				
			Gwanda	W.B.L.	31	3	
		Kiyran-dongo	Olepo				
			Gwanda				
			Mpologoma	W.B.L.	43	2	
	Buruli	Kigumba	Mpologoma				
			Bukalasa	W.B.	42	3	
	Bujenje	—	Bukalasa				
			Gwanda	W.B.	43	2	
South Bunyoro	Buganya	—	Bukalasa				Infection
			Gwanda	W.B.	25	1	localized
	Buhaguzi	—	Bukalasa				Infection very
			Gwanda	W.B.L.	15	1	localized
	Bugangazi	—	Bukalasa				
			Gwanda	—	—	0	
	Buyaga	—	Bukalasa				
			Gwanda				
			Mpologoma	—	—	0	

[a]W=wilting; B=blight; L=leaf spotting.

[b]0=no plants wilted; 1=very few plants wilted; 2=few plants wilted; 3=average number of plants wilted (50%); 4=most plants wilted; 5=all plants wilted.

planted stems wilted when they were 25--45 cm tall (i.e., about 3 months old). New shoots tried to replace the wilted ones.

Some old, heavily infected fields had stems whose roots had rotted. The rotting could be an indirect effect of the disease. In recently infected mature fields, roots were quite small and quite few in numbers.

In the districts of Lango, the percentage of infected fields varied from 3% in Otuke County to 84%. In some parts of Moroto the severity of infection was quite variable (Table 1). Infection tended to be more serious on cassava planted in poor soils.

The incidence and seriousness of infections were greatest in South Nile districts, particularly in the subcounties of Attiak, Nyapea, and Paidha of Okoro County. These areas border Zaire, and the soils are sandy and poor. Severe wilting of very young cassava plants was observed, and it had greatly reduced the establishment and growth of the crops. Initial stems originating from planted stakes had wilted, and new shoots had come up to replace the wilted ones such that an 8-month-old cassava plant appeared as if it were 3 months old. The percentage of infected fields and the severity of infection were quite high (Table 1). Varieties Tongolo, Sanja, and Terengule, believed to be Zairian-derived, appeared most susceptible. Ayivu and the western part of Terego County of Central Nile also had high incidence and severity of infection.

Infection, however, was nonexistent in South Bunyoro district of Western Province. Thus Buganda, Busoga, and certain parts of the western provinces of the country had no infection.

DISCUSSION

Cassava bacterial blight is widespread in the country. This implies that the disease must have been in the country for quite a long time but was

never recognized earlier. We are sure that this disease must have been in the country much earlier than 1970. Farmers in Nile are known to have complained about the drying of cassava stems and leaves as early as 1970–71, but the symptoms were locally mistaken to be the effect of cassava mite and mosaic, and no steps taken to report to the appropriate authorities.

In an attempt to contain the disease within the already-infected area, the government has prohibited movement of cassava, any cassava parts, any cassava by-products, or any cassava vegetative material from neighbouring countries and between provinces within Uganda (Statutory Instrument no. 27 1977).

The wilting of primary shoots of plants that are apparently less than 6 months old, as well as their compensatory replacement by new shoots, is an indication that infected stakes are a source of primary infection. Infected stakes have been known to be an important means of dissemination of the pathogen (Lozano and Booth 1974; Lozano and Sequeria 1973; Lue and Chon 1972; Maraite and Meyer 1975).

The rotting of roots may be an indirect effect of the disease. It is known that *X. manihotis* travels systematically through vascular tissues and that vascular discoloration may spread into and infect roots (Lozano and Booth 1974). Unfortunately, no isolations were made from the rotten roots, and, thus, the presence or absence of the pathogen cannot be confirmed.

The seriousness of the disease in Nile Province and other localized areas in the country is almost certainly associated with poor soil. The soils of Nile Province are mainly sandy loam or sandy-clay loam with a base exchange complex of less than 40%. It is possible that this low fertility may render the crops more susceptible to the disease.This observation has been made by many workers in other parts of the world. In Zaire, Hahn and William (1973) reported that the disease was more severe on poor, sandy soils. Similar reports were made by Maraite and Meyer (1975), and the observation was similar in Nigeria (Terry 1975).

X. manihotis has never been recorded in Uganda. In Africa, the nearest country to Uganda where this disease is known to occur is Zaire (Maraite and Meyer 1975). Local information has revealed that farmers in the West Nile prefer the short-term, high-yielding varieties of Zaire and that importing them into Uganda is common. The varieties locally known in Nile province as Tongolo, Sanja, Yakobo, and Terengule are known to be Zairian-derived. It is most likely that this disease came to Uganda through planting materials from Zaire.The fact that certain parts of Nile Province bordering Zaire have the highest and most severe infections indicates that this area was the centre of initial infection.

The spread of cassava bacterial blight in Uganda is more than was expected and needs further investigation. Insects and mites have been known to transmit bacterial diseases over long distances, and cassava mite, which is a major problem in Uganda, is blown by wind over long distances. Variegated grasshoppers and whiteflies are known to be associated with cassava. It is possible that these may play a role in the transmission of the pathogen. Work on the parts played by these arthropods in transmitting the pathogen is planned.

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INSECT DISSEMINATION OF *XANTHOMONAS MANIHOTIS* TO CASSAVA IN THE PEOPLE'S REPUBLIC OF CONGO

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From four leaf-eating insect species, we detected the causal agent of cassava bacterial blight, *Xanthomonas manihotis* by immunofluorescence. The insects were *Chrysolagria cuprina, Gonocephalum simplex, Ischnotrachelus* sp., and *Zonocerus variegatus*. We found the pathogen in the feces and in the alimentary canal of *C. cuprina, Ischnotrachelus* sp., and *Z.variegatus* that had fed on infected cassava leaves of test plants. The presence during the rainy season of these viable pathogenic bacteria in the digestive system, feces, and occasionally on the exoskeleton of these insects suggests that they are disseminators of the cassava blight pathogen.

Détection par immunofluorescence de l'agent responsable de *Xanthomonas manihotis*, brûlure bactérienne du manioc, chez quatre espèces d'insectes phyllophages: *Chrysolagria cuprina, Gonocephalum simplex, Ischnotrachelus* sp., et *Zonocerus variegatus*. Des pathogènes ont été trouvés dans les fèces et le canal alimentaire de *C. cuprina, Ischnotrachelus* sp., et *Z. variegatus* qui avaient consommé des feuilles infestées sur les plantes expérimentales. L'existence de ces bactéries pathogènes dans l'appareil digestif, dans les fèces et quelquefois sur l'exosquelette de ces insectes en saison humide permet d'envisager qu'ils transmettent la brûlure bactérienne.

Cassava, which is one of the most important perennial tropical food crops, is affected by a serious bacterial disease — the cassava bacterial blight (CBB) — caused by *Xanthomonas manihotis*. Symptoms of the disease, which appear during the rainy season, sometimes are associated with injuries on plants due to insect feeding (Fig. 1), especially in Plateau Bateké region and in Pool region. This observation raises the question: what responsibility do insects have for the dissemination and transmission of *X. manihotis*?

Some authors have suggested that insects can be disseminators of pathogenic bacteria (Buddenhagen and Elsasser 1962; Faure et al. n.d.; Hayward and Waterston 1965; Klement et al. 1964). But no evidence has yet been published for their role in the spread of cassava bacterial blight. Thus, our preliminary investigation was to determine the role of insects in the dissemination of bacterial blight pathogen in People's Republic of Congo.

MATERIALS AND METHODS

We collected insects from diseased cassava plants during the rainy season (1980) with a net or by hand at Kombé (Pool region) and Odziba (Plateau Bateké region). The insects inventoried and tested as possible carriers of *X. manihotis* were *Chrysolagria cuprina, Ischnotrachelus* sp., *Gonocephalum simplex, Zonocerus variegatus*, and *Pseudotheraptus devastans*.

After transporting them to the laboratory, we used some for isolations and immunofluorescence testing, and the others were placed on caged diseased cassava plants for feeding trials.

Insects collected in the diseased fields were placed individually in sterile test tubes containing 5 ml of deionized water with one drop of tween 80 and shaken for 30 minutes. The wash water of each tube was used for isolation on YPDA medium (yeast extract 5 g, bacto-peptone 5 g, dextrose 5 g, agar 15 g, H_2O 1000 ml, pH 7.2) and immunofluorescence testing.

Each washed insect was then crushed in sterile water and allowed to stand 15 minutes. A loopful of the resulting suspension was streaked on YPDA medium, and the remaining liquid was used in an immunofluorescence test and for inoculation of the leaves of cassava test plants by the leaf infiltration method (Kaiser and Vakili 1978).

A sample of 30 insects *C. cuprina, Ischnotrachelus* sp. and *Z. variegatus* collected from diseased plants were washed in sterile water and dissected. We excised the alimentary canal, which was crushed in sterile water. The resulting suspension was used for immunofluorescence, isolation, and inoculation tests.

For immunofluorescence examination, the indirect method (Daniel and Boher 1978) was used with the antiserum prepared against whole cells of a strain of *X. manihotis* (A 113-2) isolated from diseased cassava plants in Congo. The specificity of the antiserum was tested against 60 strains of bacteria recovered from cassava phyllosphere and insect microflora. A loopful of the suspension from the wash water with the ground alimentary canal was heat-fixed on a slide, stained with fluorescein-antibody by the indirect method and observed under a microscope with reflected ultraviolet light (Leitz orthoplan).

C. cuprina, Ischnotrachelus sp., and *Z. variegatus* were allowed to feed on caged diseased cassava plants. After feeding periods of 24 hours, the insects were transferred to sterile petri dishes and the feces were collected 12 hours later. The feces were then placed in sterile test tubes with 5 ml of deionized water and shaken 15 minutes. The resulting suspension was streaked on YPDA medium, used for immunofluorescence testing, and assayed for the presence of *X. manihotis* by the leaf-infiltration method.

For each positive isolation, two isolates of *X. manihotis* were tested for pathogenicity. To verify the pathogenicity of *X. manihotis*, we used the leaf-infiltration method with the susceptible variety Mpembé. We then assayed the samples by infiltrating 10 spots per leaf with two replications. A positive infiltration produced a water-soaked, angular lesion.

RESULTS

Most insect-feeding damage appears to be caused by three species *C. cuprina, Ischnotrachelus* sp., and *Z. variegatus*. The species *G. simplex* can cause serious damage to foliage but is not largely distributed in the fields of Congo. *P. devastans* punctures stems, inducing cankers and occasionally defoliation. The damage of the leaf-eating insects is usually done during the rainy season, although important populations of *C. cuprina, Z. variegatus*, and *P. devastans* may be found in the dry season as well.

In the field, the feeding sites of *C. cuprina, Ischnotrachelus* sp., and *Z. variegatus* are often associated with bacterial lesions.

X. manihotis, pathogenic to cassava, was detected by immunofluorescence and isolated from four insect species collected from naturally infested fields (Kombé, Odziba) (Table 1). Insects that carried pathogenic bacteria were of the same species that caused damage to the foliage of cassava plants. These were the leaf-chewing Coleoptera (*C. cuprina, Ischnotrachelus* sp., *G. simplex*) and the grasshopper (*Z. variegatus*). In our experiment we were unable to detect by immunofluorescence or to isolate the CBB pathogen from *P. devastans* collected from diseased fields. However, 20% of the leaf-eating insects collected carried viable pathogenic bacteria (Table 1).

Fig. 1. *Effects of* Xanthomonas manihotis.

The pathogenicity of 95 *X. manihotis* cultures isolated from insects was verified. All isolates induced watery lesions on plants. These isolates were similar in colony, morphology, physiology, biochemistry, and pathogenicity to *X. manihotis*, isolated from cassava bacterial blight lesions, and to collection strains.

X. manihotis was occasionally detected and isolated from the wash water of 2% of the insects from the field. Viable pathogenic *X. manihotis* was also detected and isolated from the alimentary canal and feces of three insect species *C. cuprina, Ischnotrachelus* sp., and *Z. variegatus* (Table 2). These results indicate that the pathogen remains viable and retains its pathogenicity in the digestive system of these insects and even after passing through it. Preliminary results on survival of *X. manihotis* in *Z. variegatus* feces indicate that it remains viable for up to 4 months at room temperature (22–24°C).

Table 1. Detection by immunofluorescence (IF) and isolation on YPDA medium of *X. manihotis* from insect species collected from diseased cassava plantings.

Insect species	No. tested	Wash water		Insect grinding	
		IF	Isolation	IF	Isolation
Chrysolagria cuprina	105	11	1	41	23
Gonocephalum simplex	12	0	0	7	4
Ischnotrachelus sp.	297	21	5	137	54
Pseudotheraptus devastans	50	0	0	0	0
Zonocerus variegatus	100	7	5	63	28

Table 2. Detection, isolation, and pathogenicity of *X. manihotis* from insects and feces collected from cages containing diseased plants.

	Ischnotrachelus sp.			*Chrysolagria cuprina*			*Zonocerus variegatus*		
	IF	Isolation	Path.	IF	Isolation	Path.	IF	Isolation	Path.
Digestive system	12	5	+	15	12	+	14	2	+
Exoskeleton (wash water)	3	1	+	0	0	0	4	2	+
Feces	8	3	+	5	4	+	14	9	+

However, only 40% of the insects detected as carriers of *X. manihotis* by immunofluorescence contained viable pathogenic bacteria (growth on YPDA medium). The same percentage of viability was observed from the pathogen in insect feces. This finding suggests that the level of bacterial inoculum is reduced in the digestive system of the insects and in the feces or is inhibited by insect bacterial microflora on YPDA medium.

The internal presence of *X. manihotis* was verified throughout the rainy season (October–March) and in part of the dry season (till August, last data) for two species *Z. variegatus* and *C. cuprina*. *Ischnotrachelus* sp., however, either did not occur during the dry season or was at a low level of population.

DISCUSSION

The objective of our investigations was to determine the role of insects in the dissemination of cassava bacterial blight in People's Republic of Congo. The preliminary results demonstrate that under field conditions *X. manihotis* can be carried by foliar-feeding insect species *C. cuprina*, *Ischnotrachelus* sp., and *Z. variegatus*. The species *G. simplex* was also shown to disseminate *X. manihotis*, but the population level of this insect in the field is low.

The presence of viable pathogenic bacteria in the digestive system, feces, and occasionally on the exoskeleton of *C. cuprina*, *Ischnotrachelus* sp., and *Z. variegatus* in the rainy season (period when the dissemination occurs) suggests that these insects act as carriers of *X. manihotis* and disseminate the disease. The transfer of bacterial inocula by insects from diseased to healthy plants is favoured by the capacity of the pathogen to survive as an epiphyte on aerial parts of the cassava plant (Daniel and Boher 1978; Persley 1978). Only 40% of the insects that exhibited the presence of the pathogen at immunofluorescence yielded viable *X. manihotis* isolates. This finding may reflect the insect's ability to reduce the viable cells of bacterial inoculum or the inhibitory effect of some bacterial strains of insect microflora on *X. manihotis*.

The active inoculation of plants by feeding insects still remains to be demonstrated. At present, taking our results into account, it is unclear whether the bacterial lesions originate at feeding sites or whether insects prefer to feed on diseased tissues. However injuries caused by feeding insects favour lesion development. The efficiency with which the three insect species disseminate *X. manihotis* is unknown, especially for long distances.

CASSAVA ROOT ROT DUE TO *ARMILLARIELLA TABESCENS* IN THE PEOPLE'S REPUBLIC OF CONGO

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Armillariella tabescens is the pathogenic agent of cassava root rot in the People's Republic of Congo. Studies carried out in many areas have shown that cassava is attacked by external "subterranean" rhizomorphs and internal "subcortical" rhizomorphs. Agricultural practices, such as the use of stakes that are already infected and the often very long period (3–4 years) during which roots are preserved in the ground contribute to the maintenance of the disease. Farmers are receiving advice concerning measures aimed at reducing losses, such as harvesting roots and marketing them after 3 years. However, these measures are encountering problems deriving from marketing and road conditions and the farmers' reluctance to abandon traditional practices.

Armillariella tabescens (Fr) Sing est l'agent pathogène du pourridié du manioc en République Populaire du Congo. Les prospections effectuées dans de nombreuses localités ont montré que *A. tabescens* édifie dans le sol des rhizomorphes "subterranea" (organes infectieux) externes et des rhizomorphes "subcorticalis" internes, par rapport aux organes attaqués dans les tubercules. L'utilisation pendant les bouturages de boutures déjà infectées, la période de conservation des tubercules dans le sol souvent très longue (3 à 4 ans) sont des pratiques culturales qui contribuent au maintien de la maladie. Certaines mesures tendant à réduire les pertes et qui consistent à arracher les tubercules après 3 ans de conservation dans le sol, et les commercialiser sont conseillées aux paysans. Cependant leur application se heurte à des obstacles liés aux problèmes de commercialisation, à l'état de l'infrastructure routière et la psychologie des paysans.

In the Congo, cassava is the most widespread crop and the main source of carbohydrates among all the starchy tuber and root plants cultivated (cassava, sweet potatoes, yams, and taro). In cassava-producing areas, cultivation takes place in general in small plots, where other crops are sometimes grown along with it.

Several factors limit the production of cassava at present in the Congo, for example:

- The widespread distribution, in cassava-producing areas, of local varieties with low yields;
- The traditional methods of preparing the soil; and
- The presence of numerous pests and diseases either recently introduced (for example, the cassava bacteriosis caused by *Xanthomonas manihotis*), or long established, among which are the rots due to the genus *Armillariella*.

Because of its widespread distribution and the losses for which it is responsible, the *Armillariella* rot is the most important.

Armillariella rot has been observed in several areas in the southern part of the country. Plantations in the following localities and their periphery have been prospected (Fig. 1): Odziba Mbe, Kinkala Boko, Mindouli, Kindamba, Vingza, Madingou, Sibiti, Komono, Mossendjo Mayoko, Makabana, Mont-belo, the Mayombe Forest Massif, and Pointe-noire. In the savanna, farmers use the burn-beating (Makany 1976) technique of cultivation; in the forest, slash-and-burn. Where these two types of vegetation exist, both techiques are used.

SYMPTOMS

Symptoms have been observed on plants 2–4 years old. In general, when plants other than cassava are attacked by *Armillariella*, the aerial symptoms appear after one or more roots have been attacked. On cassava, the symptoms and their evolution vary according to whether the plant is a creeping or erect variety. On erect varieties, the symptoms appear when all roots (tuberous or non-tuberous) are attacked and destroyed. These symptoms begin with a yellowing of the foliar lobes, followed by desiccation and detachment of the petiole from the stalk. The stalk and branches

Fig. 1. *Localities studied in the southern section of the People's Republic of Congo.*

become denuded and then die. On creeping plants, these symptoms have not been observed, even on plants whose subterranean system is destroyed.

On the stalk the symptoms first appear on the neck; the skin cracks or splits and exposes blackish mycelial filaments that propagate in palmette-shaped forms. On erect plants, these palmettes progress along the stem up to 1 or 1.5 m from the ground (Fig. 2). On creeping plants, they colonize

Fig. 2. *Cassava stalk with mycelium patches between skin and core.*

Fig. 3. *Cassava stalk (4 years old) with "subterranean" rhizomorphs.*

only the base of the neck and do not progress higher than 20 cm above ground. In the soil, near the neck of the plants numerous long cylindrical, branched "subterranean" rhizomorphs have been observed (Fig. 3). These rhizomorphs are either flattened against the stake or root and creep along it or have their base anchored on the stake or root and propagate in the soil apically. Transverse and longitudinal sections show a structure similar to that described by Townsend (1954) and Guillaumin (1967, 1968). During the rainy season, the mycelium at the neck level differentiates to produce the numerous carpophores set out in tufts and supported by annulus-free stems.

Diseased roots are covered with a network of brownish, branched "subterranean" rhizomorphs, the initiators of the infection (Fig. 4). On severely infected roots, it is possible to observe on the skin a network of black palmettes that develop in the central cylinder and emerge in a vertical fan on the root's surface. Their extremities are white initially, then turn brown, then black (Fig. 5). These organs constitute a sort of pseudosclerotia. The longitudinal section of a piece of infected root exhibits, in the central cylinder, many palmettes 0.5–2.5 cm wide, growing centripetally or centrifugally by the apex. In this central cylinder, black lines stretch over several centimetres or outline oval black surfaces that result from the discoloration of certain parts of the palmettes. These dark masses (Fig. 6), similar to those that develop on the skin, are said to be pseudosclerotia (Campbell 1934). In the central area of the cylinder, the palmettes differ from the white, ribbon-like "subcortical" rhizomorphs, which look like fine strands (Fig. 7 and 8).

INFECTION

The infection of the cassava roots may come from "subterranean" rhizomorphs according to a mechanism that has already been described (L. Roger, personal communication). The rhizomorphs first spread over the root and branch some undifferentiated mycelial filaments into the skin at various points, adhering by "anchor" cells. From the infection point, the mycelial filaments settle in the skin, then aggregate into palmettes. These palmettes then spread either between the skin and the periphery of the central cylinder or toward the centre of the central cylinder. The progression of the palmettes is accompanied by the release of chemical substances that degrade the surrounding tissues.

The other source of infection is infected planting material, the roots being attacked by simple generalization of the pathogenic agent from the stake planted in the soil. In humid conditions, the pathogenic agent reaches the root through its peduncle.

Rain and humidity contribute to the development of the pathogenic agent and the propagation of "subterranean" rhizomorphs in the soil. Infected roots collected during the rainy season are covered with many growing rhizomorphs of a brownish colour. During the dry season, infected roots have very few rhizomorphs showing growth activity. Further, my observations have shown that the disease propagates much more rapidly in areas where rain and humidity are constant, particularly in the forest zone.

Temperature, mentioned as a factor intervening in the initiation and development of rhizomorphs, does not appear to have much effect on rhizomorphogenesis. In the various prospected localities where rhizomorphs were observed on infected roots, temperatures range from 20 to 30°C during both dry and rainy seasons.

TOPOGRAPHY AND AGE OF PLANTS

In cassava plantations located on sloping terrain, the plants most infected are found at the foot of hills in areas most often very humid and badly drained in comparison with the slopes or hilltops.

The greatest damage has been noted in 3- or 4-year-old cassava plantations. Damage increases when the period of preservation of the roots in the ground extends to 4 years.

DISCUSSION AND CONCLUSIONS

Some of the cultivation techniques practiced in the cassava-producing areas effectively contribute to the maintenance of the pathogenic agent in the ground. Cassava cultivation is practiced over small areas where the usual practice consists in harvesting the roots when needed over a period of 2–4 years. A long period of preservation exposes the roots to infection. These infected roots constitute an important source of inoculum from which the "subterranean" rhizomorphs propagate in the soil and infect other organs. In humid conditions the use of stakes that are already infected allows the development and propagation of the pathogenic agent in

Fig. 4. *Network of "subterranean" rhizomorphs covering a cassava root.*

Fig. 5. *External surface of root infected with pseudosclerotia.*

new organs (tuberous or nontuberous roots) and in the soil.

My observations in various localities have indicated that at certain times of the year the genus *Armillariella* develops carpophores at the level of the neck of the stalk. The morphology of fructifications, particularly the absence of annuluses, suggests that these symptoms are attributable to *A. tabescens*. This species, previously unknown in Central Africa, has been recorded to a much greater extent in the Mediterranean area (Tunisia) on *Eucalyptus* (Delatour 1969); in the southern United States, on forest trees (Filer and McCracken 1969); on the pecan tree in Georgia (Takass et al. 1970); on *Citrus* in Florida (Rhoads 1948); and on the quinquina in Upper Guinea (Heim and Jacques Felix 1953).

Other species of the same genus have been recorded in Central Africa and might well exist in the Congo. *A. elegans* with annulus (intermediate between *A. mellea* and *A. tabescens*) has been recorded on the coffee tree in Madagascar and Cameroon (Dadant 1963; Heim 1963). *A. mellea* with annulus has been recorded on coffee and tea in Tanzania (Wallage 1935); on tea, cocoa, and hevea in Uganda (Hansford 1937); on coffee in Malawi (Leach 1932, 1937); and on tea and conifers in Kenya (Goodchild 1958; Gibson 1960; and Olembo 1971). The others, *A. fuscipes* and *A. luteobubalina*, have not yet been described in Africa. The absence or presence of the annuluses as a feature for classification does not seem sufficient for systematic discrimination of the species. Other morphologic and cytologic features of the thalli should complement it. This would enable one to see whether species that are at present little known in Africa (*A. fuscipes* and *A. elegans*) have not been mentioned under *A. mellea*.

In some cases, the aerial symptoms usually described on plants attacked by rot have not been observed. The creeping varieties of cassava do not exhibit any aerial symptoms, despite the deterioration of their root system. Among such plants, new roots are grown above the neck and actively nourish the aerial part.

In the various localities I studied, I observed rhizomorphs on infected roots — a finding indicating that *A. tabescens* is capable of initiating "subterranean" and "subcortical" rhizomorphs on infected organs in equatorial and tropical climates.

Does temperature affect the initiation and development of rhizomorphs in tropical and equatorial climates? According to some authors, outside a range of 15 to 25°C, the initiation of the

Fig. 6. *Longitudinal section of the root (TUB) showing pseudosclerotia (PS).*

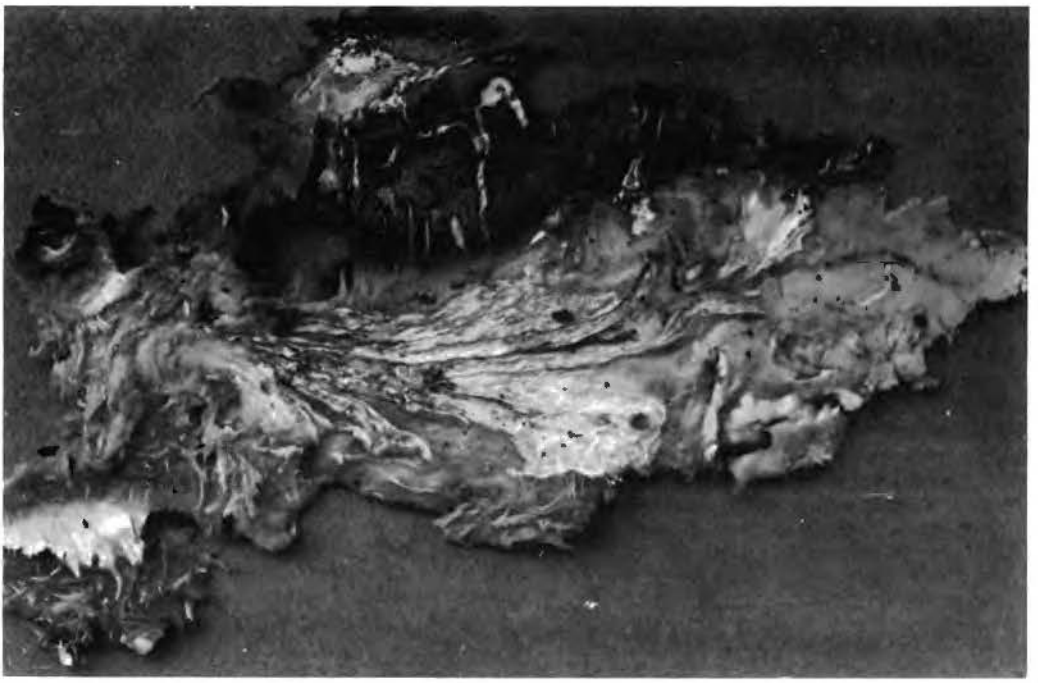

Fig. 7. *Mycelium aggregated in palmettes in central cylinder.*

rhizomorphs is slow in the soil and is inhibited at 30°C (Rishbeth 1963). According to others, the temperature has an influence on the number of rhizomorphs. According to them, the number of rhizomorphs initiated at 15°C is greater than at 25°C, but the total dry weight of the rhizomorphs is little changed (Redfern 1973). Swift (1962) mentions that the Armillaria does not differentiate rhizomorphs in tropical regions. These observations, which are quite different from mine, should be considered with a great deal of caution.

Cassava root rot due to *A. tabescens* presents a serious problem for cassava cultivation. It extends over large areas of most of the cassava-producing forest regions and is maintained by the cultivation methods traditionally practiced in these areas. Methods for combatting it (curative methods), which consist in the use of products such as

Fig. 8. *Central cylinder of a root colonized by numerous palmettes.*

Bordeaux mixture, mercuric chloride, etc., are unknown in these regions. Their application is plagued by many difficulties, and they are very expensive.

Preventive methods using genotypes that have been improved to withstand bacterial blight and mosaic disease have not yet been introduced in any program of prevention of cassava root rot due to *Armillariella* in Africa.

To reduce the most severe losses, farmers could harvest the roots earlier than is the present practice; therefore they have been asked to shorten to 2 or 3 years the period during which the roots are kept in the ground before being marketed. The advice, however, has not been widely accepted for several reasons. The farmers, whose cultivation practices are part of their heritage, cannot easily abandon them. Those who have attempted have encountered problems in routing the harvested cassava to the large urban centres and marketing it. To all this must be added the difficulties presented by road conditions, where some of the roads are barely passable at certain times of the year.

This paper was originally French; with the author's permission, it was translated into English for inclusion in these proceedings.

SCREENING FOR RESISTANCE AGAINST THE GREEN SPIDER MITE

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After a brief introduction on the history, symptoms, yield loss, biology, and behaviour of the green spider mite, the paper outlines the methods for screening cassava varieties for resistance to the pest. In Tanzania and Zanzibar, resistant clones have been identified from local and IITA germ plasm. In Nigeria, at present all available germ plasm and the 1980 seedlings have been evaluated for resistance. For this a scoring system ranging from 1 to 5 has been developed, 1 being highly resistant and 5 highly susceptible; 27 clones from the germ plasm have been identified as less susceptible. At present, these clones are being tested more intensively. The testing program includes:

- Monitoring the mite population on each clone for 12 months;
- Monitoring plant growth because the vigorously growing clones seem to withstand green spider mite effectively;
- Identifying the mechanisms of resistance, such as pubescence (shaved and unshaved leaves are compared in terms of mite population development); and
- Monitoring reproduction of the female insects (number of eggs, egg and nymph mortality, and length of time needed for each development stage).

Résultats d'une recherche sur les méthodes de sélection en vue d'introduire le caractère résistance à la teigne, précédés d'un aperçu de l'histoire, de la biologie, des symptômes et du comportement de ce ravageur. La création de cultivars résistant à la teigne constitue une solution économique à long terme. On a trouvé, en Tanzanie et à Zanzibar, des clônes résistants à la fois chez les espèces locales et le matériel génétique d'IITA. Au Nigeria, on a procédé à l'évaluation en fonction de la résistance à la teigne de toutes les espèces disponibles ainsi que des plantations de 1980, à l'aide d'une échelle de 1 à 5 où le 1 signifiait résistance élevée et le 5, haute sensibilité. Vingt-sept clônes ont été retenus pour leur résistance à la teigne et ils font actuellement l'objet de tests plus poussés comprenant:

- la surveillance de la population de teignes pendant 12 mois;
- le contrôle de la croissance des clônes, les variétés les plus vigoureuses paraissant aussi être les plus résistantes;
- l'identification des mécanismes de la résistance tels que pubescence (les feuilles duvetées étant comparées aux feuilles lisses en termes de population de teignes); et
- contrôle de la reproduction de la teigne-femelle (nombre d'oeufs, nymphes, mortalité et durée de chaque stade).

The green spider mite *Mononychellus tanajoa* was discovered in Africa about 8 years ago. Since then it has spread over East and Central Africa and now is advancing along the West African coast countries.

Because the pest is new in the agroecosystem in Africa, no natural enemies, like predators or pathogens, have yet begun to curtail its spread. Within the last 8 years, natural selection of less-susceptible cassava varieties may have begun but has had little effect on the whole situation. Fortunately, natural methods of control can be reinforced and speeded by human beings.

A biological control program is being conducted by the Commonwealth Institute of Biological Control (CIBC). Selection for resistant cultivars was first started in Tanzania by Shukla (1975) using local cassava clones. Later, IITA seedlings were screened for resistance, and in Tanzania and Zanzibar some signs of resistance were identified.

In 1979, the green spider mite appeared in Nigeria, and at the beginning of 1980 a resistance breeding program had already begun at IITA. Both the biological control program and the breeding for resistance program are carried out in close collaboration with national research institutions like the Institute for Agricultural Research and Training and the National Root Crops Research Institute in Umudike. In addition, research scholars from other African countries are trained at IITA to enable them to initiate control programs in their home countries.

The green spider mite research program in Nigeria is focusing on:

- The biology and ecology of the green spider mite;
- Breeding of resistant cultivars;
- Biological control;
- Cultural control; and
- Chemical control.

SYMPTOMS AND ECONOMICS

The green spider mite (GSM) attacks the young cassava shoots (Fig. 1); symptoms of infestation are that the young leaves remain small, unexpanded, and spiny; expanded leaves show various degrees of yellow spots that may resemble mosaic symptoms; and defoliation progresses downward from the shoots. The green spider mite, unlike the red spider mite, prefers young leaves. If red spider mite and green spider mite infest a plant together, total defoliation may occur.

Because the green spider mite was only recently observed in Nigeria, data on cassava yield losses in this country are not available. Nyiira (1975) found in his studies in Uganda that yield losses up to 40% can be expected after severe mite infestation.

ECOLOGY, BIOLOGY, AND SPREAD

The green spider mite is a dry-season pest. This fact has been confirmed in Uganda, where large mite populations occurred when the weather was dry. Rainfall washes many of the mites off the plant, although the pest is able to survive the rainy season in countable numbers.

Preliminary observations in Nigeria indicate that at the height of the dry season when cassava doesn't grow well, the green spider mite is low in numbers. The reason for this is probably that the mite feeds on young succulent shoots, which are not produced at this time of the year. Field studies done by T. Akinlosotu (personal communication) show clearly

Fig. 1. *Green spider mite attacks young shoots of cassava.*

that two population peaks occur — one at the end of the wet season (October–November) and one at the beginning of the wet season (April–May). This type of information is essential for any type of screening work.

The female and male mites are both present. The female lays eggs whether or not it is fertilized. The egg-laying life span of a female ranges from 12 to 23 days. During this time, about 70 eggs are laid. The total development from egg to adult lasts 8–13 days. The optimum temperature for egg laying is 28°C. Mites are able to lay eggs at relative humidities of 10–100%, but maximum oviposition takes place between 50 and 70% RH.

Spread and Control

The cassava GSM is spread by infested planting materials and by wind. The exact way that mites are carried on planting material is not known; probably individual mites or eggs are hidden in cavities on the stakes. The most important spread within a country is by wind. In the mornings, adult mites lower themselves from the leaves on silken threads. Even low wind currents can pick them up and carry them away. Mites can be transported by wind over long distances, and this characteristic has been reflected in the rapid spread within Nigeria.

Muaka-Toko (1979) has examined 18 different wild plant species as possible reservoirs for mite populations. His study included nine *Euphorbia* species. On none of the examined plant species could green spider mites be found. Further studies are necessary to confirm his work.

Breeding for Resistance

In conjunction with studies focusing on the pest, efforts focusing on the plant are also under way. Methods have been developed at IITA to screen available cassava germ plasm for resistance to the

Fig. 2. *Resistance to green spider mite varied markedly.*

pest, and these methods are based on symptom development, mite population development, and plant growth.

For the evaluation of the large amount of cassava material in the germ plasm and the seedling nursery, a scoring system based on symptoms allows quick and easy scoring. The scoring system comprises five categories: (1) no obvious change; (2) few whitish spots on young, unfolded and first expanded leaves; (3) shoot leaves not fully expanded, older expanded leaves covered with distinct chlorotic spots and leaf-size reduced by 25%; (4) apical leaves not expanded, reduction of leaf size to more than 50%, severe chlorosis on older leaves, and possibly infestation of older leaves; and (5) shoot dead or unproductive, older leaves infested, little or no infestation of lower, expanded leaves, and a sticky appearance.

With the help of this scoring system, we at IITA have evaluated all available germ plasm and the 1980 seedling nursery. Only plants or clones that score 1 or 2 are selected for further testing. Of a total 1100 germ-plasm entries, 20 were selected and replanted in plots measuring 5 × 3 m in two replications.

In the seedling nursery, all plants scoring 1 or 2 have been tagged and will be transplanted later. Of 200 000 plants, 400 seedlings were selected as showing high degrees of resistance.

The plants that showed resistance in the first cycle of screening (Fig. 2) are now being subjected to direct mite population counts and monitoring of plant growth.

Vertical green mite counts from shoot tip to the 10th leaf have shown that about the fourth leaf is the most suitable for such counts, in terms of handling and population density. From this, only the middle lobe of the leaf is selected for actual counts under the microscope. Altogether four leaves are selected weekly per clone. The mite population is monitored over 12 months, and the population figures are then correlated with the symptom score. It has been found that symptomless plants can harbour high mite populations.

Plant growth reflects plant vigour, which, again, is often a factor contributing to resistance. To monitor this, one tags the first folded leaf and, at weekly intervals, counts the number of leaves from the originally tagged leaf to the newest folded leaf. This is a crude method, but, with the amount of material to be handled at IITA, it is the most convenient.

A high number of clones that have been selected as green mite resistant show various degrees of pubescence on the shoot leaf, but my colleagues and I at IITA are still uncertain whether tricomes directly contribute to resistance or whether they signal indirectly another factor. To investigate further, we have developed a shaving method, which will be tested properly during the next mite season (October–November).

SCREENING RESULTS

Except for the scoring results, our data on population development and plant growth were only obtained during the wet season when the mite population was low. They are inconclusive until the next green mite season has been included. There has been only one interesting observation up till now. The control used as a susceptible check seems to be totally resistant during the wet season.

All clones in the second screening of germ plasm have been artificially infested with mites, but neither the control nor a number of selected clones has yet emerged, and to date there are no signs of mite establishment.

BIOLOGICAL CONTROL OF THE CASSAVA MEALYBUG

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The loss of a basic food supply for Africa to an exotic insect, the cassava mealybug, can be overcome through classical biological control. In the area of origin in Latin America, natural enemies (parasitoids and predators) are being searched. After basic ecological studies and quarantine processing they are shipped to Africa. Detailed studies on the biology, ecology, and behaviour of the cassava mealybug have been undertaken and are also being carried out for the newly discovered natural enemies. New methods of mealybug mass rearing for natural enemies production are being tested as well as efficient methods for the releases of the promising natural enemy species. For follow-up studies on the effectiveness of these natural enemies, life tables and key factor analyses are used. A proper economic analysis of the project may provide interesting figures about the economic benefits obtained from biological control.

Les pertes de vivres essentielles que la cochenille du manioc, insecte exotique, fait subir à l'Afrique, peuvent être évitées par la lutte biologique. On recherche les ennemis naturels de la cochenille (prédateurs ou parasites) en Amérique latine, son pays d'origine. Après quelques études biologiques élémentaires et leur mise en quarantaine, ces ennemis naturels sont expédiés en Afrique. Des recherches approfondies sont en cours sur la biologie, l'écologie et le comportement de la cochenille du manioc et des ennemis naturels récemment détectés. On expérimente de nouvelles méthodes d'élevage de ces ennemis naturels ainsi que des procédés de lâchers. L'impact des ennemis naturels est etudié a l'aide de tables de suivie et d'analyses de facteurs clé. Une analyse économique du projet peut apporter des chiffres intéressants sur la rentabilité de la lutte biologique.

Biological control has emerged as a powerful and durable pest-control technique during the last 100 years or so. Its origin, however, goes back much further, at least to about 400 AD when the Chinese placed ant nests (*Oecophylla smaragdina*) in their citrus orchards to control the citrus stink bug (Pu 1976).

In classic biological control programs against exotic pests, natural enemies are generally sought in the general area where the pest originated and are then screened under quarantine before being imported and bred in large numbers prior to release. It is hoped that the natural enemy population will increase rapidly after release, cause the pest population to decline, and then coexist with the pest, both populations persisting at very low densities.

HISTORY OF THE CASSAVA MEALYBUG

The cassava mealybug was first found in Zaire in 1973 (Hahn and Williams 1973). The insect was new and a description based on specimens collected in the People's Republic of Congo and Zaire followed in 1977 (Matile-Ferrero 1977). In 1975, a mealybug outbreak occurred in Northeastern Brazil (Albuquerque 1976). Subsequent identification showed that the mealybugs belonged to *Phenacoccus manihoti* (Matile-Ferrero 1977), previously described from Africa.

Since its first discovery, the cassava mealybug has spread very rapidly to cover almost all the cassava-growing areas along the coast from Senegal to Angola.

TAXONOMY, BIOLOGY, AND POPULATION DYNAMIC

The morphologic characteristics of *P. manihoti* leave no doubt about its origin being the Americas (Williams, D.J., personal communication). It is, therefore, agreed that the pest has been introduced accidentally from the Americas into Africa, although the exact locality from which it originated is still uncertain.

Several studies on the biology of *P. manihoti* have been carried out (Nwanze 1978; Fabres and Boussiengué 1980). In short, their results show that the life cycle from egg to reproductive adult is 24

days at 26°C. The average fecundity in the laboratory is 440 eggs per female, which may live up to 26 days.

During feeding, the cassava mealybug injects into the plant a toxin that produces strong growth disturbances, such as leaf curling, shoot growth slowing, and eventually leaf withering. The mealybugs feed generally on the stem near the growing point, on petioles, and leaves (in order of preference). The dispersal of the crawlers and the egg masses occurs passively with the wind. Humans also help in spreading the mealybug by moving infested planting materials.

The population dynamic of the cassava mealybug follows a seasonal pattern (Leuschner 1978; Fabres 1980). During the dry season the population increases rapidly to reach a self-destructing level. At this point, generally before the onset of the rainy season, the population will break down, because of lack of food, overcrowding, and entomopathogens. The survivors will eventually resettle on the newly produced shoots at the beginning of the rainy season and maintain themselves in small colonies throughout the cassava fields until the next dry season. Life-table studies carried out by IITA scientists give a causal explanation for the numerical changes in population densities (Herren and Lema, in preparation).

Intensive studies in Africa have shown that few native parasitoids and predators are attacking the cassava mealybug (Matile-Ferrero 1977; Nwanze 1978). Their impact on the mealybug population is negligible, mainly because they are not (and cannot be) specific.

The yield losses caused by the cassava mealybug may reach up to 60% for the roots and 100% for the leaves. The high losses are more a reflection of the adverse effects of the saliva toxin on growth than a product of the high number of mealybugs.

Biological Control Strategies

The first and most important task is to find the tools with which to work — natural enemies that keep the cassava mealybug under control in the areas of origin. When the area of origin is located, studies on the ecology of the host insect and natural enemies have to be undertaken. These will provide the information that researchers need to select the most-promising species rapidly. The selected enemies will then be sent to a quarantine lab to be screened for hyperparasitoids and diseases before being sent to Nigeria for further studies on biology, ecology, and behaviour. At the same time, mass culture and release methods have to be developed so that, as soon as the natural enemies are available, they can be released in experimental fields and their effectiveness checked with the life-table technique.

Today, there are already several species of parasitoids and predators in the preliminary study phase at IITA. They were found in South America by CIBC (Commonwealth Institute of Biological Control) specialists (Bennett and Yaseen 1980).

Role of IITA

IITA in cooperation with national scientists in Africa and Latin America and other international institutions proposes to provide scientific leadership in a search for a solution to the cassava mealybug problem. The main tasks of IITA are to:

- Determine the area of origin of *P. manihoti* and its natural enemies (in cooperation with CIBC);
- Initiate studies on the biology and ecology of *P. manihoti* in South America in cooperation with Centro Internacional de Agricultura Tropical (CIAT);
- Undertake studies on biology, ecology, and behaviour of the introduced natural enemies of *P. manihoti*;
- Develop methods for mass cultures and mass release of the natural enemies;
- Establish life tables for assessment of the impact of the natural enemies; and
- Analyze the economics of the biological control program.

ENTOMOPHAGOUS INSECTS ASSOCIATED WITH THE CASSAVA MEALYBUG IN THE PEOPLE'S REPUBLIC OF CONGO

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The study reported here is a contribution to the knowledge of the entomophagous insects associated with the cassava mealybug in Congo. It must be considered as a step toward the development of a reliable pest management strategy. The occurrence of several predators, parasites, and hyperparasites is reported and their relationship is studied in detail. A new species of the genus *Anagyrus* is recorded. Several Coccinellids (*Exochomus flaviventris*, *Exochomus concavus*, *Hyperaspis senegalensis*), Cecidomyiids (*Coccodiplosis citri*, *Dicrodiplosis* sp.), Lycaenid (*Spalgis lemolea*), and Anthocorid (*Cardiasthetus exiguus*) are involved in the natural regulation of the pest population. Hyperparasites (*Xyphigaster pseudococci*, *Homalotylus flaminius*, *Prochiloneurus pulchellus*) have been found attacking *Anagyrus*, *Exochomus*, and *Coccodiplosis* species. An additional Encyrtid (*Cheiloneurus cyanonotus*) develops upon the hyperparasite *Homalotylus*. Data are given on the dynamics of the entomophagous insect populations, the time of their intervention, and the rates of parasitism and predatism.

La présente étude a apporté des lumières aux connaissances sur les insectes entomophages susceptibles d'être employés au Congo dans la lutte contre la cochenille du manioc. Elle constitue un progrès pour le développement d'une stratégie sûre de lutte contre les ennemis du manioc. Elle contient les recherches détaillées effectuées sur l'apparition de plusieurs prédateurs, parasites et hyperparasites et l'action qu'ils exercent les uns sur les autres. Une nouvelle espèce du gène *Anagyrus* est mentionnée. Plusieurs coccinellidés (*Exochomus flaviventris, Exochomus concavus, Hyperaspis senegalensis*), cecidomyidés (*Coccodiplosis citri, Dicrodiplosis* sp.), lycaenidés (*Spalgis lemolea*), et anthocoridés (*Cardiasthetus exiguus*) jouent un rôle dans le contrôle naturel de la population des ennemis du manioc. Les hyperparasites (*Xyphigaster pseudococci, Homalotylus flaminius, Prochiloneurus pulchellus*) attaquent les espèces *Anagyrus, Exochomus* et *Coccodiplosis*. Et une autre encyrtidé (*Cheiloneurus cyanonotus*) parasite et hyperparasite *Homalotylus*. Le document fournit des données sur la dynamique des populations d'insectes entomophages, la période de leur action et le taux de parasitisme et de destruction.

Phenacoccus manihoti appeared in cassava plantations in the Congo in 1973 (Sylvestre 1973). The rapid increase in this crop-destroyer's populations and the intensity of its ravages during the dry seasons in 1974 and 1975 led to a mission by the National Museum of Natural History (Matile-Ferrero 1976) and to a detailed morphologic study of this Pseudococcidae (Matile-Ferrero 1977).

P. manihoti is a new species, morphologically related to the Caribbean *P. surinamensis* (Williams in Bennett and Greathead 1978). Its neotropical affinities were confirmed by Matile-Ferrero (1977) who found *P. manihoti* in samples from Brazil and by Bennett and Greathead (1978) who attribute the recent pullulations of pseudococcins on cassava in Amazonia to this species (Albuquerque 1977).

The presence of *P. manihoti* in Central Africa and its rapid spread and sudden increase in population are due to a recent accidental introduction from South America.

The problem presented by *P. manihoti*, therefore, is the presence of a pest in a new biogeographic area away from its natural biological controls. In this case, experts are considering applying biological control techniques by introducing entomophagous insects (Greathead 1978). To this end, the laboratories of the Commonwealth Institute for Biological Control in Trinidad have undertaken an inventory of the entomophagous insects of *Phenacoccus* in South America and the breeding of a number of species that appear interesting in this regard. A campaign for the introduction and release of parasites originating in the New World was already organized in Zaire in 1978 (Girling 1978).

For the Congo, where an identical operation is at the project stage (Girling 1979), my colleagues and I judged it indispensable to begin with a study of the local entomofauna associated with the mealybug and an analysis of the biocenotic equilibrium established following the pest's intro-

duction. Following a year of collections, field observations, and laboratory studies, we can now provide the first quantitative report giving a fairly complete, faithful picture of *P. manihoti*'s biocenosis.

ENTOMOCENOSIS COMPONENTS

PRIMARY ENTOMOPHAGOUS INSECTS

The primary entomophagous insects belong to five main orders: the Hymenoptera Chalcididae (Encyrtidae), which are internal parasites of the mealybug, and the Coleoptera (Coccinellidae), Diptera (Cecidomyiidae), Hemiptera (Anthocoridae), and Lepidoptera (Lycaenidae), which are predators of the mealybug.

The parasites recorded to date in Zaire and the Congo belong to the genus *Anagyrus*, which comprises many species that are primary parasites of Pseudococcidae. In Zaire there are two species, one of which is related to *A. bugandaensis* (Girling 1979); in the Congo, only one species appears to be interesting from an ecological point of view. It does not correspond to any description made to date, and a morphological study is at present under way.

Anagyrus n.sp. prefers to parasitize the mealybug's third larval stages and the young females. Its attack is usually limited to a few sections of the colony; thus, there appears to be little host-seeking activity for egg-laying. The highest rates of parasitism are observed at the peak of gradation of *P. manihoti* populations (September–October 1979). They then fluctuate between 3 and 5% of potential hosts. A paper on the intervention of *Anagyrus* n.sp. during the mealybug's period of pullulation is in preparation.

Of the Coccinellidae predators, *Exochomus flaviventris*, *E. concavus*, and *Hyperaspis senegalensis* are the three dominant species. Although all three have been described in Ethiopia and observed in many countries of intertropical Africa, little work has been done on their biology or control potential (Annecke 1969; Brown 1972, 1974). Species belonging to these two genera are very polyphagous and prey on the Homoptera Pseudococcidae, Diaspididae, Lecanidae, Aphididae, and Aleyrodidae (Thompson and Simmonds 1965).

The intervention of these three species within *P. manihoti*'s biocenosis is complementary. *E. flaviventris* appears in June–July at the beginning of the mealybug's population gradation, and it can still be found at the onset of the first rains when the mealybug becomes scarce. Its maximum population density is observed in September, at the peak of gradation. *E. concavus* is found mostly at the beginning of the retrogradation; its numbers are smaller and its appearance very short-lived. *H. senegalensis* appears at the end of the gradation and, like the preceding species, remains in the plantations for only 4 or 5 weeks. During one dry season, the prevalences for the three species gathered by various methods were *E. flaviventris*, 38.1%, *E. concavus*, 23.5%, and *H. senegalensis*, 38.4%.

In the absence of data on the biology and behaviour of these species, it is difficult to estimate these predators' control potential. Our first quantitative report shows that when the host is in the pullulation phase, and for a total density of 1000 mealybugs per shoot apex, it is possible to collect on each apical colony an average of 12–15 *E. flaviventris* or *H. senegalensis* adults.

Other species less closely associated with the mealybug are also collected on the colonies. Thus, we have inventoried *Scymnus rufifrons*, *S. plebejus*, *Sthethorus endruedyi*, *Serangium giffardi*, *Nephus derroni*, and *Platynaspis* sp.

Three species of Cecidomyiid predators were obtained in hatchers by Matile-Ferrero in 1976: *Coccodiplosis citri*, *Dicrodiplosis* sp., and *Lestodiplosis* related to the *Aonidiella*. During the 1978 and 1979 campaigns, on samples of old larvae taken in colonies of *P. manihoti*, I found only the first two species. The second is probably a predator of *F. virgata*, like *L. aonidiellae* in the Congo (Harris 1968). The genera *Dicrodiplosis* and *Coccodiplosis* are represented in Ethiopia by many species, all of which are predators of Pseudococcidae. *C. citri* is known in South Africa on *Planococcus citri* (Barnes 1935).

The most numerous species on mealybug populations in the Congo is *C. citri*, which alone comprises 90% of the individuals raised in hatchers. Fluctuations in this predator's numbers show two maxima at the beginning and end of the gradation of the pest's populations. As with Coccinellidae, I can only give a rough estimate of the relationship between the density of the host and that of the predator. An apex harbouring 1000 or 1200 mealybugs in all stages holds a maximum count of 50–60 old *C. citri* larvae (August and November 1979).

The Lycaenidae is *Spalgis lemolea* whose caterpillars prey on the eggs and all development stages of some Pseudococcidae and Lecanidae. This species is already known for attacks on *F. virgata* and several species of *Pseudococcus* of Central Africa (Stempffer 1957). The onisciform caterpillars, covered with waxy debris from *Phenacoccus*, hide among their prey. The originality of the

biology and morphology of this species' larval and nymphal stages has sparked many studies, the latest being that of Hinton (1974). The presence of this species is constant, regardless of the size of the mealybug population, but its numbers remain low and there are no noticeable fluctuations in relation to the host's population dynamics.

With regard to Anthocoridae predators, when the host is in the pullulation phase, isolated individuals of *Cardiasthetus exiguus* are regularly found, in hatchers and on limed traps. Very little is known of this species' biology and predatory behaviour, but it is reputed to be extremely polyphagous. Locally, it should be noted within *P. manihoti*'s biocenosis.

Secondary and Tertiary Parasites

The secondary and tertiary parasites are the Hymenoptera Encyrtidae who parasitize the primary entomophagous insects, behaving as hyperparasites.

Collected for the first time in Zaire (Risbec 1958) on populations of *Planococcus citri*, *Xyphigaster pseudococci* was found again in 1974 in Sao Tomé as a parasite of *Coccodiplosis coffea* (Prinsloo 1979). I found it parasitizing *C. citri* larvae within *P. manihoti* colonies and can, therefore, confirm its status as a parasite of Cecidomyiids while recording its first appearance in the Congo and on a new host. Its presence in the biocenosis is very discreet.

Homalotylus flaminius is a cosmopolitan species parasitizing Coccinellidae (Tachikawa 1974). It has been found in Africa on numerous hosts, among them *H. senegalensis* (Tachikawa 1963). I have not found any mention of its parasitizing *E. concavus* or *flaviventris*. Yet it has been observed only on these two hosts in the Congo. It is a gregarious parasite, attacking mainly old *Exochomus* larvae (three or four adults per host). It intervenes fairly late in the development of the predator's populations (October–November 1975), and its rates of parasitism are about 7–10%.

H. flaminius is in turn parasitized by *Cheiloneurus cyanonotus*. Species of this genus are frequently recorded in Africa as primary parasites of cochineal insects or coccinellas (Annecke 1971). Yet their status is that of a hyperparasite (with a few exceptions, Tachikawa 1974) and *C. orbitalis* is known to parasitize the genus *Homalotylus*.

Prochiloneurus pulchellus is known in Ethiopia as a hyperparasite of Pseudococcidae through species of the genus *Pseudococcus*. Within *P. manihoti*'s biocenosis, it behaves in fact as a parasite of *Anagyrus* n.sp. It intervenes very late in the gradation mechanism (end November) and, on very low populations of *Anagyrus* n.sp., may reach rates of parasitism of about 30%.

Conclusions

The entomocenosis associated with *P. manihoti* populations in the Congo is very diversified, in regard to both the organisms it comprises and their behaviour within mealybug colonies. Five orders of insects represented by at least 12 different species participate in the same ecosystem and contribute to the control of the pest's populations. The entomophagous parasites prey on all the Homoptera's stages of development one after the other. The Coccinellidae and the Lycaenidae eat the eggs and the females before the secretion of the ovisac; the Cecidomyiidae eat the eggs and the young larvae; the Anthocoridae feed on later stages of development and the *Anagyrus* parasitize third stages and young females. There is no doubt that their simultaneous or successive action throughout the pest's population gradation helps to reduce the impact of the mealybug on its host plant. A study of the control potential of the primary entomophagous parasites, together with an analysis of the depressive role of the hyperparasites, is at present under way.

In the face of the uncontrolled development of this exotic mealybug, researchers are thus witnessing the spectacular adaptation of a great variety of entomophagous insects, with a relay action that continues throughout the pest's evolution cycle. However, the phenomenon is largely one of polyphagous or oliphagous organisms—in this case of predators—while the parasite fauna, which has a generally more specific, even monophagous, diet, is extremely scarce.

This fact underlies the move toward the introduction of parasites originating in the New World. This enrichment of the biocenosis with specific elements cannot but result in the reinforcement of the control potential of the indigenous entomophagous insects.

My thanks to the specialists who kindly identified most of the entomophagi mentioned above.

This paper was originally French; with the author's permission, it was translated into English for inclusion in these proceedings.

DYNAMICS OF CASSAVA MEALYBUG POPULATIONS IN THE PEOPLE'S REPUBLIC OF CONGO

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I undertook a study of the succession of generations of *Phenacoccus manihoti* and the variations in population sizes. I used the method of Benassy (1961) adapted by Fabres (1979) and counts of the populations on leaves and shoot apexes and found extreme variation on apexes, ranging from 1–3 mealybugs in the rainy season to more than 70 during pullulation. The role of rain in halting the growth in population is clear. There were three successive generations in the dry season, enabling the pest's population to multiply by a factor of almost 20. Altogether there were nine generations.

Recherche sur la succession de générations de *Phenacoccus manihoti* et les variations de densité de population. Le compte des cochenilles sous les feuilles et les apexes, selon la méthode Benassy (1961) adaptée par Fabres (1979) a révélé des variations extrêmes allant de 1 à 3 au cours de la saison des pluies à plus de 70 cochenilles en période de pullulation. Le rôle de la pluie sur la croissance de la population est globalement mis en évidence. En saison sèche, trois générations se sont succédées et la population des ravageurs a multiplié ses effectifs par un facteur voisin de 20, ce qui a donné neuf générations pour l'ensemble.

Phenacoccus manihoti was recently introduced into Central Africa from the New World. This crop-destroying mealybug has caused spectacular havoc in cassava plantations and has therefore aroused a great deal of interest. At a colloquium in Zaire in 1978, many contributors mentioned the problem of cassava mealybug infestation and described methods for controlling its populations.

However, the number of studies dealing with the bioecology of *P. manihoti* is relatively small: Ezumah and Knight (1978) and Leuschner (1978) mentioned the proliferation of the mealybug in the dry season but did not quantify it or use a cassava stem infestation index (% infected), whereas Nwanze et al. (1980) dealt with the bug's bioecological parameters without looking at its population dynamics.

Thus this study, the results of which are described below, is the first to provide quantified information on the variations in cassava mealybug populations and on the intrinsic or climatic factors that govern them.

METHODS

This study was conducted in fields of cassava of the "m'pembe" strain, near Brazzaville (Kombé Farm). The data gathered and analyzed cover the year 1979. The subject of the study was the succession of generations of *P. manihoti* and the variations in population sizes.

The method used for the succession of generations was developed by Benassy (1961) and applied to tropical countries by Fabres (1979). It consists in taking a weekly vegetation sample and making a count of all bugs found, tabulated according to their stage of development. Depending on the season, counts varied from 200 to 1000 mealybugs. The counts make it possible to find out the proportion of each stage within the colony and to determine precisely the succession of generations during the climatic year. A detailed analysis of the results of this study was made (Fabres 1980), and here I will summarize only the essential data.

I used the method of sight counts in the field to determine variations in population size. Each week 100 shoot apexes were picked at random in the sampling fields; the presence or absence of the bug was determined, and the rate of infestation of the apexes and leaves. On 30 apexes, all bugs were counted and the different stages noted. Each week, therefore, I obtained a percentage of apexes infested, an average rate of infestation, and a mean value of the number of mealybugs per apex. A parallel study was conducted on random samples of leaves, six leaves to an apex, or 180 leaves per week.

Annual variations in the percentage of apexes infested and the rate of infestation are given in Table 1. The relationships between average num-

Table 1. Variations in percentages of shoot apexes infested and average rates of infestation.

Date (1979)	Infested apexes (%)	Infestation rate (%)
13/6	24	6
29/6	51	12
16/7	56	15
30/7	66	20
14/8	46	27
29/8	83	40
13/9	70	49
29/9	96	45
14/10	100	83
13/10	100	100
14/11	100	100

bers of mealybugs per apex and absolute maxima are given in Table 2. Variations in densities over time are shown in Fig. 1, together with a daily rainfall curve and a diagram of the successive generations. Note that the numbering of generations is artificial, generation 1 being the one with which the count began.

RESULTS

The variation in the number of *P. manihoti* per apex is extreme, ranging from 1–3 mealybugs per apex in the rainy season to more than 70 in a period of pullulation. Absolute maxima may reach 600 or 700 bugs per apex, as on 20 September 1979 (Table 2). On leaf organs, densities are lower, not exceeding 300 or 400 mealybugs per leaf (Table 2).

The changes in the percentage of apexes infested in relation to the total number of plants examined show that the propagation of the infestation is very rapid. Although in June only 20% of apexes were infested, in July the number had reached 65% (Table 1). By the end of September, mealybugs were found on all apexes. The rate of infestation is more gradual, and it was not until October that maximum (100%) infestation had occurred, from 45% in September.

The curve in Fig. 1 shows the precise evolution of the average population per apex. In February, when the count began, densities were very low. They fluctuated between 0 and 10 until June. From July on, there occurred a rapid increase in the population that brought the density to some 70 bugs per apex at the end of October. This increase was not constant but occurred in three successive stages in June–July, August–September, and September–October. From November on, almost all the mealybugs had disappeared with the advent of the torrential rains marking the beginning of the season. Densities were very low in comparison with February numbers.

The role of rain in halting population growth is clear. The increase in density between June and October coincided with the dry season and the complete cessation of rainfall. The bug's near disappearance and continuing low population levels corresponded to the onset of the rains and their continuing abundance. The short dry period in March was marked by a slight increase in *P. manihoti* densities.

In this seasonal context of the variations in population sizes, a study of the succession of generations provides additional information making it possible to interpret the curve in Fig. 1: generations 1, 2, and 3 ensured the transition between rainy and dry seasons and showed low densities. Generations 1 and 2 developed during the season of light rains, generations 7, 8, and 9 during the season of heavy, torrential rains, during which the mealybug became very scarce. Generations 4, 5, and 6 were those responsible for the proliferation of the mealybug in the dry season, and the three stages noted on the curve of variations corresponded to the development of these three successive generations.

Table 2. Mealybug densities in rainy and dry seasons — average numbers and absolute maxima from counts on shoot apexes and leaves.

Date (1979)	Average mealybugs/ apex	Maximum	Average mealybugs/ leaf	Maximum
2/8	30.4	62	7.5	50
9/8	37.2	84	3.6	38
16/8	25.5	120	4.5	41
23/8	35.0	77	2.0	75
30/8	35.7	50	3.6	74
20/9	67.1	679	18.5	125
27/10	70.0	252	43.3	336

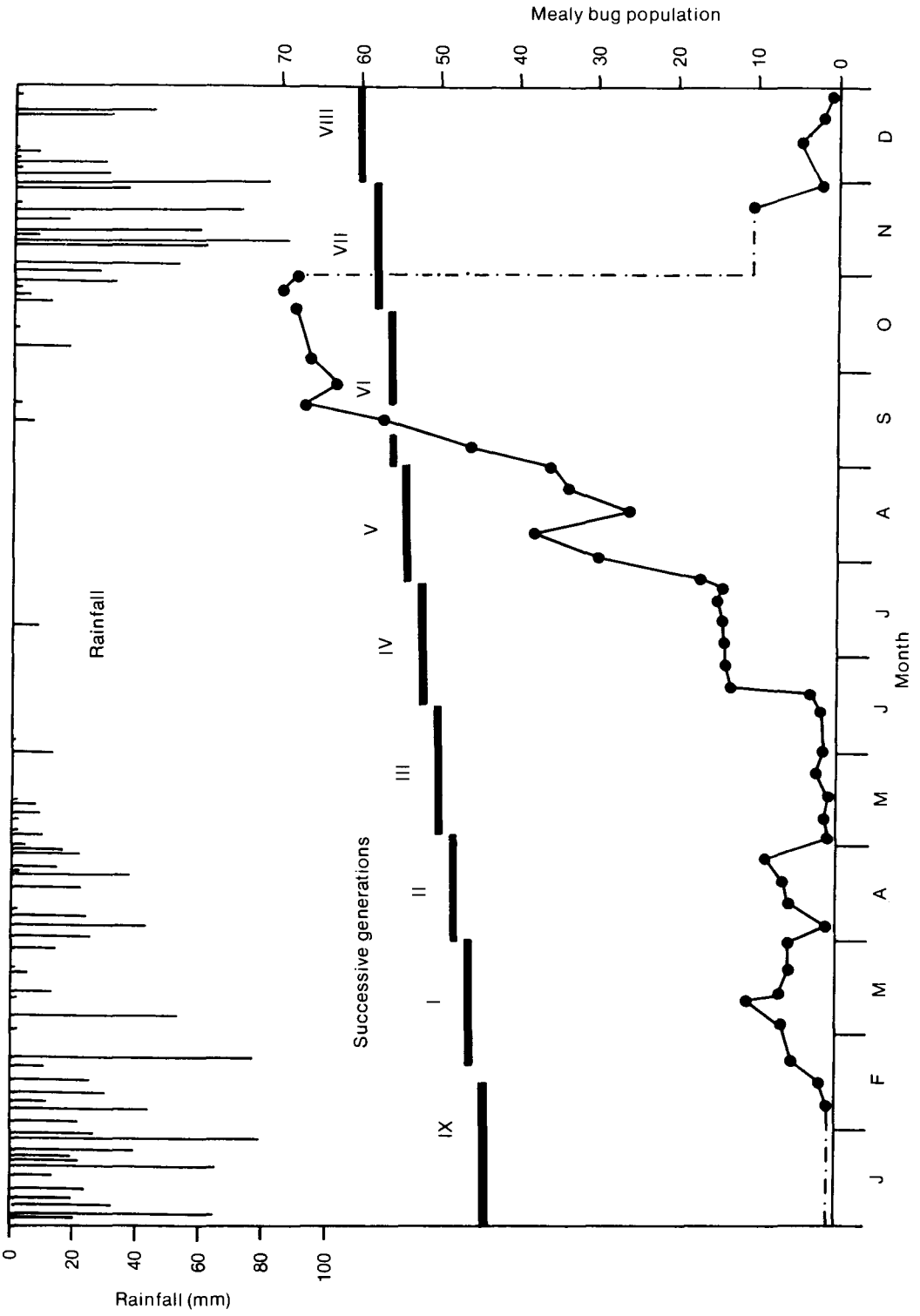

Fig. 1. *Mealybug population.*

CONCLUSIONS

This study is the first to quantify precisely the variations in *P. manihoti* population sizes during a climatic year. Following the work of Ezumah and Knight (1978) and Nwanze (1978), I have demonstrated the mechanical role of rainfall and calculated its impact on population density. This mechanism explains the swift disappearance of the colonies at the onset of the rainy season.

The role played by the three successive generations in the dry season is fundamental, enabling this pest's population to multiply by a factor of almost 20. This phenomenon is due to the Pseudococcidae's enormous multiplication potential. It was in fact determined, during a previous study (Fabres 1980), that the intrinsic rate of multiplication (rm) is 0.15 at 26°C and 75% relative humidity and that the generation time is between 28 and 33 days in the dry season.

The results of this study are directly related to the current concern with the control of this pest. Awareness of the mechanisms of variation in *P. manihoti* population sizes and the factors to which they are due should lead to the development of agronomic control methods. The use of early varieties of cassava, which develop their roots before proliferation occurs, has already been considered. It should also be possible to reduce the densities of generations 5 and 6 to prevent pullulation.

In line with the biological control programs being developed in Central and West Africa, the information I have gathered on a parasite-free population represents the indispensable basic data that, following the introduction of exotic New World parasites, will make it possible to compare the fluctuations in the pest's densities and measure the parasites' regulating capacity.

This paper was originally French; with the author's permission, it was translated into English for inclusion in these proceedings.

CONSUMPTION PATTERNS AND THEIR IMPLICATIONS FOR RESEARCH AND PRODUCTION IN TROPICAL AFRICA

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With the exception of Nigeria, the countries in the African root crops belt are experiencing low growth rates in real income. One of the ways in which this trend is manifested is changes in dietary habits. Average Nigerians seem to be substituting rice and wheat for root crops, in their diet, whereas average consumers in the other countries seem to be substituting root crops for rice and wheat. In future, root crops consumption will likely decline in Nigeria but increase in the other countries. For the whole region, there is likely to be a surplus of production over consumption needs of root crops in general in the future. However, there would be deficits of specific root crops in specific countries. A surplus of one root crop cannot offset a deficit of another because one is not a perfect substitute for the other. Also, a surplus in one country may not offset a deficit in another because trade in the commodities is limited. There is therefore a need to develop trade in the commodities; there is also need to encourage research in and production of the root crops in which deficits of production over consumption are likely to occur in the future.

Le revenu réel des pays compris dans la ceinture de production de plantes-racines, exception faite du Nigeria, progresse lentement. L'un des effets de cette augmentation est l'évolution des habitudes alimentaires de la population. Il semble que le Nigerian moyen remplace les tubercules alimentaires par le riz et le blé alors que dans d'autres pays le consommateur moyen substitue les tubercules au riz et au blé. La consommation de plantes-racines diminuera probablement au Nigeria mais elle augmentera dans les autres pays. Il y aura donc probablement un excédent de tubercules. Cependant, il pourrait quand même y avoir un déficit de certaines plantes-racines dans quelques pays, qui ne pourra être compensé par le surplus d'approvisionnement d'autres espèces, les substituts parfaits étant souvent rares. De même, l'excédent de plantes-racines dans un pays ne pourra compenser la disette prévalant dans un autre, le commerce des biens étant très limité dans ces régions. Il faut donc encourager la recherche sur l'augmentation de la production des cultures susceptibles d'être déficitaires.

During 1970–75, Africa produced 42% of the world production of cassava and 18% of yams and cocoyams combined (FAO 1971–76). Cassava, yam, cocoyam, and perhaps sweet potato are the staples of many people of tropical Africa just as millet, sorghum, or maize is a staple of other low-income peoples of the world. Because of the present world economic situation of high energy prices, inflation, and unemployment, most of the countries in tropical Africa are experiencing low rates of growth of or declining real income. Under such a situation, root crops are likely to assume greater importance in the diets of the people.

My objective in this paper is to reappraise the relative importance of cassava, yams, cocoyams, and sweet potato in tropical Africa in the light of changing economic conditions and suggest research and production strategies through which the importance of the root crops can be most efficiently realized. The paper is based partly on time-series data generated by the International Bank for Reconstruction and Development (IBRD), the Food and Agriculture Organization of the United Nations (FAO), and the United States Department of Agriculture (USDA) and partly on farm-management studies carried out in Nigeria, Ghana, and Zaire.

AFRICAN ROOT CROPS BELT

The African production of cassava, yam, cocoyam, and sweet potato is concentrated in the countries lying within 15° of both sides of the equator — the African root crops belt; production in other African countries is relatively unimportant (FAO 1971–76). From 1970 to 1975, most of the countries within the belt cultivated an average of between 0.04 hectares and 0.15 hectares per person annually. This was 28% of the per-person area of arable lands cultivated in the belt annually. The area is also the belt of production of such tropical

industrial crops as cocoa, rubber, oil palm, and timber.

Of the countries in the belt, Central African Republic, Togo, People's Republic of Congo, Liberia, Gabon, Comoros, Equatorial Guinea, and Guinea-Bissau had populations of 2.5 million or less in mid-1976 (IBRD 1978) and, thus, are not included in this analysis. Up-to-date, time-series data are unavailable for Mozambique, Uganda, Burundi, Rwanda, and Benin, so they are also excluded from the analysis even though their total populations are greater than 2.5 million. My analysis is therefore based on Nigeria, Zaire, Tanzania, Ghana, Madagascar, Cameroon, and Ivory Coast. It is hoped that the conclusions reached are applicable to the entire belt. The seven countries account for nearly 80% of the mid-1976 population (IBRD 1978) and also nearly 80% of 1970–76 annual average area under root crops in the entire belt (FAO 1971–76).

Nigeria alone accounts for more than 50% of the mid-1976 population and more than 40% of the 1970–76 annual average areas under root crops.

Relative Importance of Individual Root Crops

Cassava accounted for about 65% of the total area cultivated with root crops, yam accounted for about 15%, and cocoyam and sweet potato accounted for about 10% each in 1970–75 (FAO 1971–76). Cassava production and consumption are evenly distributed throughout the belt, but yam and cocoyam production and consumption are concentrated in the countries of West Africa (Nigeria, Ghana, Cameroon, and Ivory Coast), and sweet potato production and consumption are concentrated in the countries of East Africa (Tanzania, Madagascar, and Zaire).

In 1970–75, root crops (cassava, yam, cocoyam, and sweet potato) contributed 38% of the average person's daily energy intake in the root crops production belt. Of the 38%, 22% was from cassava, 10% from yam, 4% from cocoyam, and only 2% from sweet potato. In comparison, 43% came from grains, 8% from bananas and plantains, 7% from pulses, and 3% from meat, dairy products, etc.[1] Hence, root crops, especially cassava, are major sources of dietary energy in tropical Africa at present.

Although in the western half of the belt cassava and yam are of about equal popularity, cassava is by far the most popular of all the root crops when the whole belt is considered. Nevertheless, the popularity of a root crop in tropical Africa cannot be determined on the basis of area or contribution to dietary consumption because some root crops have cultural values in certain areas within the belt.

Importance of Root Crops in the Future

The importance of root crops as a source of dietary energy in future will depend on what happens to real income in the belt. In developing countries, rice and wheat are eaten primarily by high-income consumers, whereas root crops, maize, millet, and sorghum are low-income consumers' staples — root crops in root crop-production regions and maize or millets and sorghum in grain-production regions.

Although individuals may not increase the quantity of root crops that they consume in a year as incomes decline, annual average per-person consumption increases because more people begin to substitute root crops for grains in their diets.

With the exception of Nigeria, major countries in the African root crops belt experienced little growth or even declining real income in 1970–76. Zaire, Tanzania, Cameroon, and Ivory Coast experienced low rates of growth of real income, whereas Ghana and Madagascar experienced declining real income in the period (Table 1). Available consumption figures show that an average Nigerian has started to substitute grains, especially rice and wheat, for root crops in his or her diet, whereas in countries with low rates of growth or declines in real income an average consumer is substituting root crops for grains, especially rice and wheat, between 1968–72 and 1973–77 (Fig. 1 and 2). In Nigeria, the annual average per-person consumption of root crops declined from 524 kg in 1968–72 to 518 kg in 1973–77 at an average annual compound rate of 0.2%; the annual average per-person consumption of rice and wheat increased from 10 kg in 1968–72 to 17 kg in 1973–77 at an annual average compound rate of 11.2%. In the countries with low rates of growth or declines in real income, the weighted (with population) annual average per-person consumption of root crops increased from 332 kg in 1968–72 to 336 kg in 1973–77 at an annual average compound rate of 0.3%, the weighted annual average per-person consumption of rice and wheat declining from 37 kg in 1968–72 to 34 kg in 1973–77 at an annual average compound rate of 0.3%.

An average annual compound rate of decline of

[1] Figures are calculated from production (USDA 1971–76) and trade (UN 1971–76) records.

Table 1. Population, totals (1976) and growth rates (1970–76), and GNPs per capita (1976) and growth rates (1970–76) for major countries in the African root crops belt.

Country	Population		GNP per capita	
	Mid-1976 ('000s)	Growth rate, 1970–76 (%)	1976 (U.S. $ million)	Growth rate, 1970–76 (%)
Nigeria	77056	2.6	400	5.4
Zaire	25389	2.7	130	0.4
Tanzania	15136	2.7	180	1.7
Ghana	10310	2.9	370	−0.7
Madagascar	9112	3.1	200	−2.3
Cameroon	7606	2.0	310	1.0
Ivory Coast	7025	3.8	650	1.9

0.2% in per-person consumption of root crops associated with annual compound rate of growth in real income of 5.4% in Nigeria shows that the effect of increases in real income on reduction in consumption of root crops is slow. It cannot be relied upon to offset the decline in root crops production, especially in a country where the level of annual per-person consumption is high. On the other hand, an increase of 4 kg, from 332 kg to 336 kg, in countries with low rates of growth or of declines in real income could be significant in total demand in countries where the population is large and increasing.

IBRD estimates show that, of the 43 tropical African countries for which data were available, 25 experienced annual compound growth rate in gross national product (GNP) of 1.0% or less and of these 25, 13 had negative growth in 1970–76 (IBRD 1978). Of the 25 countries with low rates of growth or declining real income, 13 are in the root-crops production belt. The only countries of the African root crops belt with GNP compound growth of 2.0% or more in 1970–76 were Nigeria, People's Republic of the Congo, and Gabon. People's Republic of the Congo and Gabon together had less than 2 million people in 1976 (IBRD 1978).

The current world economic situation, especially with respect to petroleum shortages and inflation, suggests that the downward trend in real income in tropical Africa, except in oil-producing countries, will continue for some time and that root crops will likely assume greater importance in the diets of the people in the region.

To determine the future importance of root crops in the region, I projected the annual total production and consumption of root crops in the major countries of the African root crops belt to the year 1995. In projecting production, I assumed that the 1961–77 production trend would be maintained. In projecting consumption, I assumed the 1970–76 annual compound rates of growth of GNP per person and of population as estimated for each country by IBRD (1978) and income elasticity of demand for each root crop as estimated by FAO (1971).

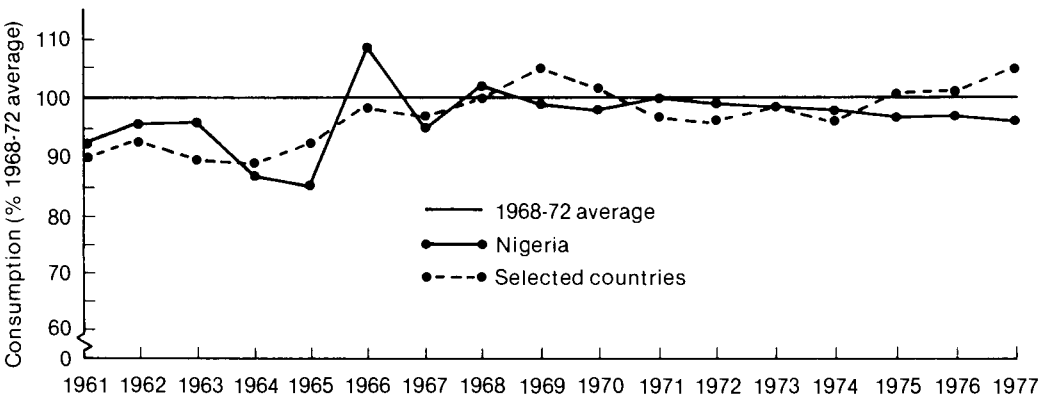

Fig. 1. *Indices (1968–72 average = 100%) of per-person consumption of root crops in Nigeria and in selected countries in the African root crops belt, 1961–1971.*

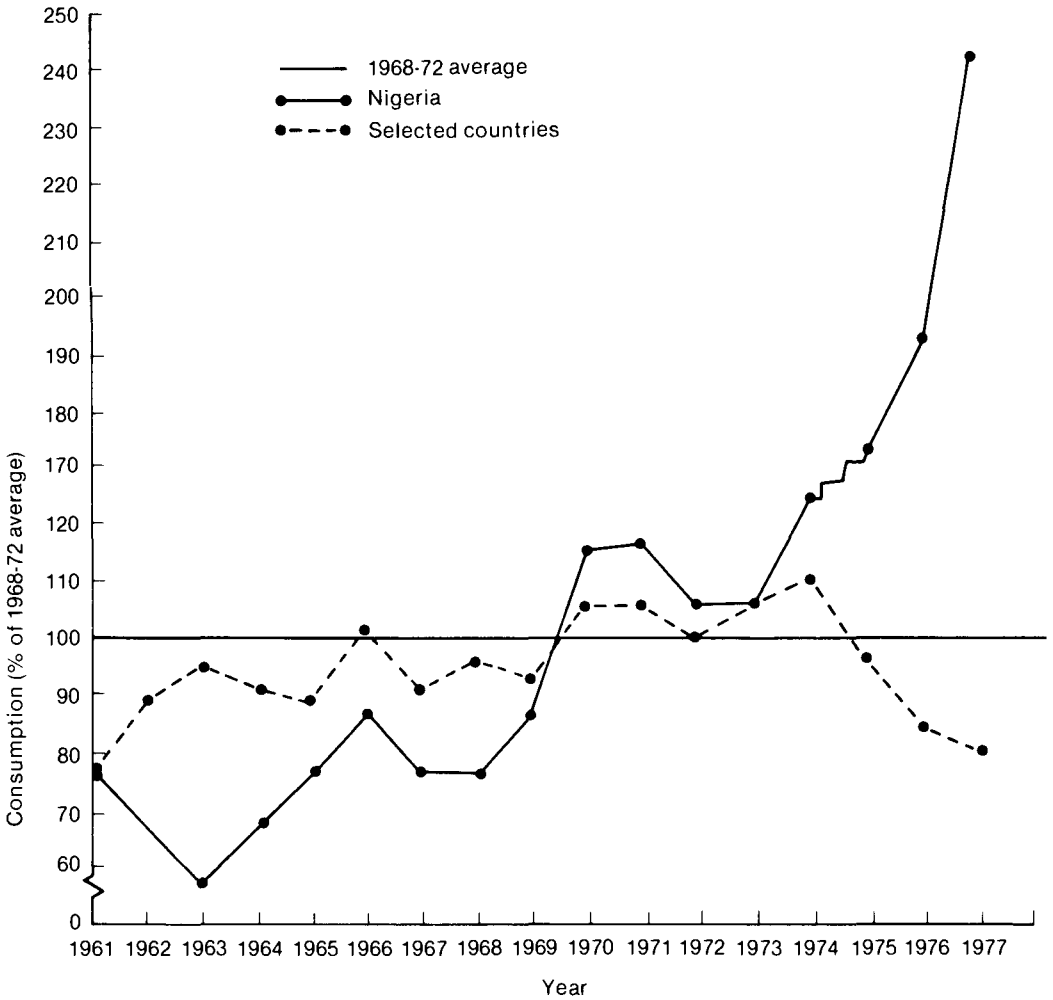

Fig. 2. *Indices (1968–72 average = 100%) of per-person consumption of rice and wheat in Nigeria and in selected countries in the African root crops belt, 1961–77.*

On the basis of these assumptions, the production of root crop (R) in country (N) in year t, $P_{R,N}(t)$, is estimated as $P_{R,N}(1977)(1 + G_{R,N})^T$ where $P_{R,N}(1977)$ = 1977 production trend estimate for root crop R for country N (tonnes); $G_{R,N}$ = annual compound rate of growth of production of R in N during 1961–77 (%); and T = time interval between 1977 and t (years). $P_{R,N}(1977)$ is estimated as log $P_{R,N}(1977) = a + bT$ where T = time interval (16 years) between 1961 and 1977. The consumption of root crop R in country N in year t, $C_{R,N}(t)$, is estimated as $C_{R,N}(1977)[1 + (L_N + I_N E_{R,N})]^T$ where $C_{R,N}(1977)$ = 1977 consumption trend estimate for root crop R for country N (tonnes); L_N = annual compound rate of growth of population in country N for 1970–76 (%); I_N = annual compound rate of growth of GNP per person in country N for 1970–76 (%); $E_{R,N}$ = income elasticity of demand for root crop R in country N; and T = time interval between 1977 and t (years); $C_{R,N}(1977)$ is estimated as log $C_{R,N}(1977) = a + bT$ where T = time interval (16 years) between 1961 and 1977 (Table 2, Fig. 3).

Without population projections, it is not possible to estimate future consumption on a per-person basis. Yet the low rates of growth or declines in real income and income elasticities of demand of less than zero suggest that per-person consumption of the root crops will be higher in 1995 than in 1977 in countries other than Nigeria. Despite this, at 1961–77 rates of growth of production and at 1970–76 rates of growth in real income and population, by 1995 the belt as a whole would generate a surplus of production over consumption

needs of more than 4 Mt of root crops. Most of the surplus would be generated in Nigeria where per-person consumption is expected to decline.

The assumption of continuation of 1961–77 rate of production to 1995 is perhaps the most subjective of all the assumptions behind the projections. It implies that substitutions in resource allocation will not take place. However, in Nigeria where a high rate of increase in GNP is expected it is likely that resources will be shifted from root-crop to grain production because demand for grains will be higher than for root crops. In the other countries resources will likely be shifted from high-cost grains to root crops. Then, the deficits for those countries would be lower and the surpluses higher than projected.

In analyses of actual data on root crops in tropical Africa, production is generally equated with consumption because recorded trade on the commodities between nations is insignificant. Nevertheless, surpluses and deficits occur from year to year, absorbed as fluctuations in returns to producers. The available data on market prices for root crops show not only seasonal and locational differences but also major fluctuations in annual averages (FAO 1971), reflecting year to year differences in supply and demand.

IMPLICATIONS

A surplus of 4 Mt for the area as a whole would mean that there would be no shortage of root crops if the commodities moved freely across national boundaries and if one root crop were a perfect substitute for another. Zaire, Tanzania, and Madagascar (all of the eastern belt countries) and Nigeria would generate surpluses; Ghana, Ivory Coast, and Cameroon (all of the western belt countries) would generate deficits of production over consumption by 1995. However, recorded trade in root crops between countries, especially among tropical African countries, is insignificant. This means that surpluses in one country do not offset deficits in another. Hence, producers in countries with a surplus of production over consumption, especially in Nigeria where income is expected to grow rapidly, would suffer capital losses and may divert their land and labour. This shift would not be adverse if the resources were diverted to tree crops such as oil palm, cocoa, rubber, etc. for which an export market exists. If, however, the resources were diverted to grains, in the production of which tropical African resources may be relatively inefficient, the effect would be adverse.

Although average yield rates for both root crops and grains are lower in tropical Africa than in the rest of the world, the difference is smaller for root crops than for grains. For example, in 1971–75, the weighted (with area harvested) annual average yield of root crops in Africa was 64% of the world average and the weighted annual average yield of cereals in Africa was 57% of the world average (FAO 1971–76). Rather than divert their resources from root-crop production to grain production, tropical African farmers would be better off if encouraged to produce root crops for export. This means that efforts should be made to establish such export markets.

Although all the root crops have more or less the same nutritive value, mainly carbohydrate, they are not perfect substitutes for each other because of local consumption habits. In most parts of south-eastern Nigeria, for instance, yam is the food security crop, and it is by far more important than any other root crop not because of its nutritional but because of its cultural value. In the area, yam is

Table 2. Estimates of production, consumption, and surplus or deficit of various root crops in major countries of the African root crops belt, 1995.

	Cassava			Yam			Cocoyam			Sweet potato		
Country	Production ('000 t)	Consumption ('000 t)	Surplus/deficit ('000 t)	Production ('000 t)	Consumption ('000 t)	Surplus/deficit ('000 t)	Production ('000 t)	Consumption ('000 t)	Surplus/deficit ('000 t)	Production ('000 t)	Consumption ('000 t)	Surplus/deficit ('000 t)
Nigeria	24179	23211	968	34287	29989	4298	2496	2803	-307	–	–	–
Cameroon	1329	1388	-59	–	–	–	1069	1129	-60	429	407	22
Ghana	963	1802	-839	1556	2713	-1157	2294	2226	68	–	–	–
Ivory Coast	2485	2074	411	3671	4170	-499	–	–	–	18	35	-17
Zaire	17445	16832	613	–	–	–	–	–	–	665	652	13
Tanzania	3700	3007	693	399	495	-96	–	–	–	–	–	–
Madagascar	2907	2580	327	–	–	–	–	–	–	342	558	-216

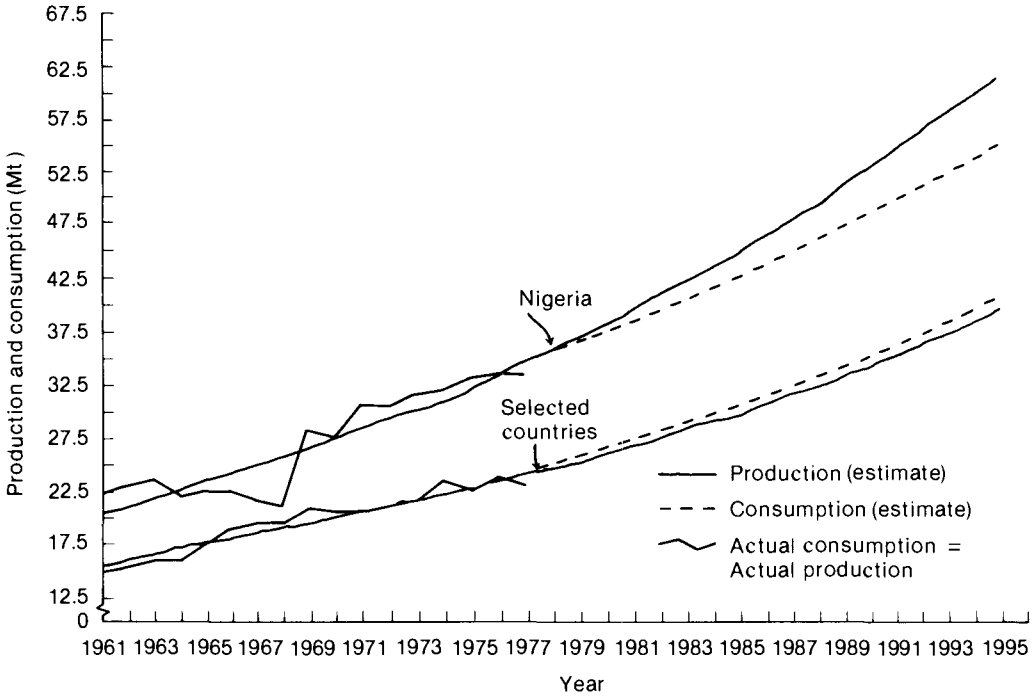

Fig. 3. *Total production and consumption of root crops in Nigeria and in selected countries in the African root crops belt: actual (1961–77) and estimated (1961–95).*

"man's crop," whereas cassava and cocoyam are "woman's crops," and all production, marketing, and consumption decisions with respect to yam are made by the male head of a household. Similar decisions with respect to cassava, cocoyam, etc. are made by female members of the household (Nweke et al. 1980). In such a situation a surplus of production over consumption in cassava would not offset an equal amount of deficit of production over consumption in yam.

The African root crop belt would generate 2.1 Mt of cassava and 2.6 Mt of yam as surpluses and only marginal deficits in cocoyam and sweet potato by 1995. The marginal deficit in sweet potato is important, because it is mainly in one country, namely Madagascar. The surplus of production over consumption of cassava would be generated in Nigeria and in eastern belt countries; countries in the western belt would generate deficits of cassava production over consumption. The surplus of production over consumption of yam would be generated only in Nigeria; the surplus in that country would be large enough to offset major deficits in Ghana, Ivory Coast, and Tanzania if trade in the commodity were developed among these countries.

The surplus of more than 4 Mt of yams in Nigeria would be at a high cost because compared with production of other food crops, yam production is very labour-intensive (Table 3).

Producing 1 Mcal from yam takes nearly three and a half times the amount of labour required to produce the same amount of calories from cassava. In most places yam is grown on huge mounds and also staked. The tasks involved are labour-intensive; mounding is necessary to enhance drainage in yam plots because the yam tuber is susceptible to rot under waterlogged conditions.

In addition, surplus yam output would be more difficult than surplus cassava output to dispose of without major capital losses to the producers. Its high production costs are not offset by potential uses; apart from its cultural value the utility of yam is limited to human consumption. In contrast, cassava has uses in livestock feed, industrial starch,

Table 3. Labour requirements for production of various root crops in Nigeria

Crop	Mandays/ha	Mandays/Mt	Mandays/Mcal
Yam	325	45	69.31
Cassava	183	21	20.57
Maize	90	121	35.51
Rice	215	145	59.92

etc. There is, therefore, a major need for new technology that would reduce yam production costs. Such technology could be mechanical methods of mounding and staking for yam or, preferably, breeding of yam varieties that are resistant to waterlogged conditions. Such efforts should be in addition to attempts now under way at the National Root Crops Research Institute, Umudike, Nigeria, and at the International Institute of Tropical Agriculture, Ibadan, Nigeria, to develop yam planting materials from seeds and stem rather than from the tuber, which is the edible part.

RESEARCH AND PRODUCTION STRATEGIES

Given the 1961–77 production trend for various root crops, 1970–76 annual compound rates of growth of GNP per person and population, and income elasticities of demand for various root crops, one may assume that the African belt will generate a surplus of root crops in general in future. However, there would be major deficits in specific countries and in specific root crops. It is necessary to encourage trade in root crops among the countries of the African root crop belt so that surplus in one country offsets deficits in another. In the absence of such trade, producers in countries with surpluses will suffer capital losses and could divert their resources to less-efficient uses; consumers in countries with deficits would pay high prices for root crops.

Surpluses generated in yam would be at high costs because of the high production costs. In areas where yam does not have a high cultural value, resources are more efficiently used in cassava production than in yam production because a unit of calorie is cheaper to produce from cassava than from yam and because cassava has uses other than for human consumption and, hence, surplus production of cassava is more easily disposed of without capital losses to the producers than is surplus production of yam.

Where yam must be produced, probably because of its high cultural value, there is need for development of cost reduction technologies, including planting materials from seed and stems as well as yam varieties with tubers and foliage resistant to rot under waterlogged conditions. Such varieties would be grown on flat beds rather than on mounds and would not need staking. These developments would significantly reduce yam production labour directly by eliminating mounding and staking and indirectly by facilitating mechanization of yam cultivation. One of the major bottlenecks to mechanization of yam production where the soil and sociologic factors such as land tenure are conducive to mechanization is the heavy power that would be needed to make huge yam mounds.

I acknowledge gratefully the useful comments made by Professor F.O.C. Ezedinma.

PROBLEMS OF CASSAVA PRODUCTION IN MALAWI

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Cassava is grown throughout Malawi, particularly along the Lakeshore where it is one of the major food crops. Production is low due to land availability, farmers' preferences, marketing, storage, farming systems, diseases, etc. Recently, there has been a marked drop in the marketing of cassava chips — from 8100 t in 1974 to 2000 t in 1979.

On cultive le manioc dans tout le Malawi mais plus intensivement sur les bords du lac du même nom où il constitue l'une des grandes cultures vivrières. La production est limitée par le manque de terres, les maladies, les préférences des fermiers, les modes de commercialisation, d'entreposage et de culture. Le marché des chips a accusé une baisse sensible, passant de 8 100 tonnes en 1974 à 2 000 tonnes seulement en 1979.

Cassava is one of the most important staple food crops in Malawi, particularly in Karonga, Rumphi, Nkhata Bay, Nkhota-kota, Salima, and Mangochi districts, which are all along the Lakeshore, and it forms an important part of the farming systems throughout the country.

There are more than 300 varieties of cassava being grown at the moment. There is a possibility that some of these varieties are the same but that their names have been changed as they have been moved from one place to another. Most of the varieties being grown in the southern and parts of the central region of Malawi came from Mozambique between the 17th and the 19th centuries through the traders and people migrating between the two countries. Similarly, in the northern and parts of the central region, the varieties being grown came from Tanzania and Mozambique. In 1967, there were 75 000 ha of cassava and 43 000 ha of sweet potatoes, and the area has remained static. Some reports even indicate that it is declining (Jocoby 1967; Sauti 1980).

Men are involved in the opening of the land from bush, and, thereafter, the women are responsible for day-to-day management of the crop (Mhone, personal communication). Where there are distinct seasonal differences, that is, dry and wet seasons, cassava is planted at the beginning of the rainy season and harvested after 9–12 months. Cassava fields are small and on average are about 0.2 ha. The yields are low.

Land is one of the limiting factors in cassava production in Malawi, and there is very little hope of increasing the land available for cassava cultivation. Waterlogging along the riverbanks and in most of the dambos results, the following season, in the fields being abandoned or, yields being much lower than expected (10 t / ha), due to rotting.

FARMERS' PREFERENCES

Farmers' preferences and the farming systems within each ecological region affect the amount of land available for cassava production. In some districts, such as Nsanje, Chikwawa, Kasungu, and Mzimba, cassava is a subsistence crop or is treated as a minor cash crop. Whatever cassava is grown in these areas is eaten as a snack, and cassava flour is used for brewing. Cotton, maize, groundnuts, beans, and tobacco are the major crops. Cassava is grown as a pure crop if the farmer intends growing it for sale; otherwise, it is grown on the edges of the plots. Cassava is grown on marginal soils and on lands that would have been fallow, and occasionally it is used as the first crop on virgin land.

Approximately 90% of the cassava being grown is sweet and matures within 9 or 12 months. If left in the ground for long periods, the roots start to lignify. Under such circumstances, the farmers are forced to harvest the crop early when the roots are relatively small; hence the potential of the crops is not exploited.

Along the Lakeshore, from Nkhota-kota to Karonga, cassava has been the main staple food. However, the opening of rice irrigation schemes has begun a gradual change in the eating habits in

this area. Cassava is now being supplemented with rice and maize. Now, farmers are not solely dependent on cassava, and this shift has resulted in reductions of the area cultivated with cassava. Unlike in the southern region, 95% of the cassava along the Lakeshore is bitter.

DISEASES AND PESTS

Disease is a major biologic constraint on cassava production in Malawi, particularly cassava mosaic disease (CMD), which is transmitted by the whitefly. This disease was very severe in the 1974–75 season, especially in the Chiweta/Mlowe area along the northern shores of Lake Malawi. Most local cultivars are susceptible to the disease. Affected crops give very low yields (2–10 t/ha of fresh roots in 12–24 months) compared with potential yields (more than 20 t/ha for the same period). The problem is aggravated by the fact that farmers due to lack of technical advice and absence or shortage of clean planting material continue planting infected stakes (Table 1). Surprisingly, mosaic virus disease is not much of a problem in the central and the southern regions where sweet cultivars are predominant. Bacterial blight disease seems not to be present.

The whitefly (*Bemisia tabaci*), elegant grasshopper (*Zonocerus elegans*), red spider mite (*Tetranychus* spp.), cassava scale (*Aonidiomytillus* spp.), and mealybug are found in Malawi causing various degrees of damage on the cassava crop (Terry and MacIntyre 1975). Of the four pests, the whitefly is considered the most serious. Red spider mites have only been reported in northern Karonga and at Mkondezi in Nkhata Bay. Termites and ants have been known to cause problems during crop establishment, particularly during dry spells in areas where they exist.

MARKETING AND ALTERNATIVE CROPS

Despite the Agricultural Development and Marketing Cooperation (Admarc)'s interest in buying dried cassava chips, the quantity of chips being offered for sale to Admarc has dropped considerably since 1974. In 1974, the quantity purchased was 8100 t; a year later the amount was only 2600 t; and in 1979 was only 1700 t. If the decrease in the quantity of cassava chips being sold to Admarc is a direct reflection of the quantity of cassava being produced, then there is no doubt that cassava production in Malawi is dropping.

Unfortunately, only farmers in Mulanje, Machinga, and Thyolo sell cassava chips to Admarc. Only 16 of the 1700 t were bought from Nkhotakota and Nkhata Bay, which were the major cassava-growing areas in 1979. This reduction in purchases of chips could be attributed to several factors, for example, marketing systems and the extension emphasis on the growing of hybrid maize, which commands a higher price than cassava chips. The current price of cassava chips is 3 tambala/kg (9 tambala = U.S. $1), whereas that for maize is 6.6 tambala/kg (Salifu 1980).

Along with price differences, the best maize farmer gets yields of up to 8000 kg/ha, and the poorest hybrid maize farmer gets up to 4000 kg/ha in a good season as compared with average cassava yields of 5000 kg/ha by a good farmer and about 2000 kg/ha by a poor farmer. Under such circumstances, a good hybrid maize farmer gets a net profit of about 300 kwacha/ha (K300; 1 kwacha = U.S. $0.9) as opposed to a net profit of K150 obtained by a good cassava farmer and K100 net profit by a poor hybrid maize grower as opposed to a net profit of K30 from a poor cassava farmer. In places like Kasungu and Mulanje alternative cash crops such as tobacco, groundnuts, beans, rice, and maize have the upper hand, and in the Shire Valley, crops like cotton, rice, and guar beans are the economic crops.

In addition to yield and price disadvantages, the marketing system for cassava is not yet fully organized in the main growing areas. In Kawing, for example, most of the cassava offered for sale to Admarc goes through intermediaries who buy chips from strategic points. As yields obtained per unit area are low along the Lakeshore cassava-growing areas, farmers are not willing to offer the little they obtain to Admarc for sale.

STORAGE

Stored cassava, despite its dry state and low moisture content, becomes covered with mould and if stored too long is attacked by weevils (Extension Aids 1969). Because farmers cannot harvest large quantities of cassava and store it safely, they must leave it unharvested and the land is tied up by a crop that should have been harvested at once to make room for a new crop. Thus, under cassava, there are no incentives for farmers to expand the acreage, given the fact that they may end up with a lot of rotten or heavily lignified cassava roots.

MANAGEMENT

It is assumed by farmers that cassava is a hardy crop and therefore requires little or no attention.

Table 1. Effect of mosaic on cassava yield (t fresh weight/ha).

Planting material	Gomani		Mbundumali		Mean	
	1978	1979	1978	1979	1978	1979
Infection-free	22.73	15.45	38.17	31.03	30.45	22.26
Mild infection	10.74	21.89	32.81	21.23	21.53	21.56
Moderate infection	8.31	9.60	4.31	13.61	6.36	11.60
Severe infection	3.29	8.40	3.81	8.06	3.55	8.23

Table 2. Effect of planting date and spacing on fresh weight yields at about 1 year (kg/ha) of three varieties of cassava, Malawi.

Planting date	Cassava variety		
	Chitembwere	Mbundumali	Gomali
9 Feb 1978	48194	24802	19841
13 Mar 1978	19048	21230	18056
11 Apr 1978	8829	8333	8631
10 May 1978	8829	9226	1409
Spacing (m)			
1.2	16151	16111	16429
0.9	18849	14127	16635
0.6	18690	17143	20754

Most farmers hardly weed their fields, and, if they do, weeding is done only once. Fertilizers are not applied to cassava, and if the crop is attacked by CMD, the yields are reduced, especially when the farmer starts with diseased planting materials.

RESEARCH ACTIVITIES

Though cassava was introduced in Malawi just like other crops being grown in the country, little research has been devoted to this crop and, as such, extension advice on the crop is limited if not lacking. The crop has not been considered very economic or nutritional. The Department of Agriculture reported in 1951: "The famine brought home the value of cassava in particular, and the hope is that it will remain at its present production as a famine reserve crop." Until 1949, food crops in what was then Nyasaland (Malawi) included maize, sorghum, millets, rice, wheat, groundnuts, and pulses (Department of Agriculture 1952). It was as a result of the 1949 famine that cassava appeared under the list of food crops in 1950 and sweet potatoes in 1952. Whatever research was being carried out was on an observation basis only and continuing it was not considered important. Hence, technical information on cassava was scarce.

It was not until 1975 that research became active as a result of the outbreak of cassava mosaic virus disease. However, there has been little continuity in cassava research because of shortages in staff.

CURRENT RESEARCH STRATEGIES

In 1975, the research department of the Ministry of Agriculture and Natural Resources started looking into the cassava crop seriously. In 1978, the first Malawian was sent to IITA for training in root crops and was later appointed the coordinator of root crops in Malawi. In 1980, another officer was sent on a similar program — a move to build the cassava team.

In 1978, a national cassava collection program was initiated, and materials collected were the base for clonal studies to identify the potential of local materials.

In 1977, 15 seed lots were received from IITA and were released in 1979 for field screening on agronomic characteristics and disease resistance. About 150 lines were raised from them and are currently undergoing field observations for high-yielding and disease-resistant varieties.

The early coordinators identified Gomani, Chitembwere, and Mbundumali as being the most popular varieties in the northern region. A number of experiments were designed to explore the effects of harvest time, planting time, and application of fertilizers, and variety trials were initiated (Table 2).

The decline in cassava production is primarily attributed to the growing of low-yielding varieties and poor cultural practices. With increasing interest

in cassava, the Ministry of Agriculture and Natural Resources is establishing seed multiplication plots as sources of clean planting materials for farmers. Extensionists are encouraging farmers to plant clean materials and to rogue any plants carrying mosaic virus disease, particularly if the symptoms are seen during the establishment of the crop.

Also, a search is under way for resistant and high-yielding varieties of cassava, and researchers are screening cassava introductions from other countries. A national local collection has started with the aim of identifying local materials that are both resistant and high yielding.

Various agronomic trials, that include varieties, fertilizer inputs, appropriate cropping systems, etc. are in progress. In addition, work on improving the infrastructure in most of the cassava-growing areas is going ahead. Several institutions have shown interest in the crop and are willing to finance the cassava project both in research and production sectors. Alternative uses are being investigated, such as production of alcohol for use in motor cars, etc.

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EVALUATION OF SOME MAJOR SOILS FROM SOUTHERN NIGERIA FOR CASSAVA PRODUCTION

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A pot trial was carried out with cassava and seven benchmark soils commonly used for cassava production in the forest and derived savanna of southern Nigeria. Soils from basement complex rocks from the forest zone (Araromi, Egbeda, and Apomu series) have higher potential for cassava production than those derived from sandy sedimentary rocks (Alagba, Onne, and Nkpologu series) or sandy soil from derived savanna (Shante series). Differential N, P, K, Mg, S responses and Zn deficiency were also observed among the seven soils. The data obtained can be used as a guide for fertilizer experiments.

Expérience de culture du manioc sur sept sols différents qui forment généralement la couche arable des forêts et savanes du sud du Niger où on produit cette plante-racine. Les sols de la zone forestière (Araromi, Egbeda et Apomu) produits par l'altération du socle rocheux ont un potentiel de production plus élevé que les sols de grès (Alagba, Onne et Nkpologu) ou les sols sableux des savanes (Shante). Les sept sols ont réagi différemment à l'apport de N, P, K, Mg et S et on a pu observer des carences en Zn. Ces données peuvent servir de base pour la conduite d'expériences sur les engrais.

In the traditional bush fallow system, cassava is usually grown as the last crop because of its ability to produce a reasonable yield on low fertility soils. However, cassava can produce high yields when grown on fertile soils or with judicious fertilization. In minikit trials carried out in East Central State, Nigeria, Ezeilo (1977) reported large and economic root yield increases ranging from 21 to 181% with NPK application. A number of investigators have reported responses to N, P, and K in cassava in various cassava-growing areas in southern Nigeria (Irving 1956; Amon and Adetunji 1973; Obigbesan 1977; Obigbesan and Fayemi 1976; Kang et al. 1980). As part of the Nigerian government's effort to increase food production in the country, emphasis has been given to the use of fertilizers to increase cassava yield. For this purpose, more and better data are needed about the responses of cassava to the nutrients contained in the soils of the major cassava-growing areas of the country. As one of the initial steps for obtaining the needed information, we carried out a greenhouse trial to assess the nutrient status of seven benchmark soils widely used for cassava production in southern Nigeria.

Table 1. General information on the seven soils used in the experiment.

Soil order	Soil series	Location	USDA classification	Vegetation and land use
Alfisol	Alagba	Ikenne	Oxic paleustalf	Bush regrowth in forest area
Entisol	Apomu	IITA, Ibadan	Psammentic usthorthent	Grass fallow in forest area
Alfisol	Egbeda	IITA, Ibadan	Oxic paleustalf	Secondary forest
Entisol	Shante	Ogbomosho	Psammentic usthorthent	Derived savanna
Alfisol	Araromi	Ishoya	Oxic paleustalf	Grass fallow in forest area
Ultisol	Nkpologu	Umudike	Typic paleudult	Grass fallow in forest area
Ultisol	Onne	Onne	Typic paleudult	Bush regrowth in forest area

Table 2. Physical and chemical properties of soils used in the experiment.

Soil series	Mechanical analysis (%)			pH	Organic C (%)	Total N (%)	Bray-1 P (ppm)	Extractable cations (me/100g)			Extractable Zn (ppm)
	Sand	Silt	Clay					K	Mg	Ca	
Apomu	85	7	8	6.0	1.13	0.18	6.0	0.25	1.07	2.90	3.3
Alagba	81	9	10	6.0	1.40	0.18	1.8	0.08	2.00	3.20	2.4
Shante	91	5	4	6.4	1.10	0.08	6.0	0.33	0.07	1.70	0.8
Egbeda	70	15	15	6.4	1.60	0.29	3.0	0.60	2.40	4.10	6.8
Araromi	51	19	30	6.0	2.50	0.39	6.3	1.20	2.50	8.70	23.1
Nkpologu	87	5	8	4.9	1.40	0.13	6.9	0.08	0.50	1.20	0.7
Onne	81	7	12	4.1	1.03	0.14	41.7	0.21	0.23	0.38	1.5

Table 3. Effect of fertilizer application and soil type on height (cm) of cassava variety TMS 30395 at 5 WAP.[a]

Fertilizer treatment	Egbeda	Apomu	Alagba	Araromi	Onne	Nkpologu	Shante	Fertilizer mean
Control	19.8	21.8	13.0	18.8	15.8	17.0	14.0	17.1
NPKSMg	21.5	19.8	20.8	17.8	17.5	17.3	15.3	18.5
NPKS	20.0	18.5	21.8	16.0	18.5	14.5	16.0	18.5
NPKMg	19.8	17.8	23.8	15.5	13.5	17.5	14.0	18.3
NPSMg	21.5	19.0	19.8	17.3	20.3	16.5	16.3	18.6
NKSMg	15.8	17.5	14.8	18.0	18.3	14.0	16.0	16.3
PKSMg	21.5	19.0	18.8	20.3	15.3	13.5	15.0	17.6
Soil mean	20.0	19.3	18.9	17.9	17.0	15.8	15.5	

[a]Soil type: SE = ± 0.72; LSD 5% = 2.2; WAP = weeks after planting.

Table 4. Effect of soil type and fertilizer application on plant dry weight (g) at 12 WAP.[a]

Fertilizer treatment	Araromi	Egbeda	Apomu	Alagba	Onne	Nkpologu	Shante	Fertilizer mean
Nil	20.0	16.4	13.8	11.8	15.4	9.6	10.5	13.9
NPKSMg	23.9	19.7	21.4	20.4	15.7	16.2	14.5	18.8
NPKS	21.4	18.3	19.9	18.4	16.1	14.0	10.6	17.1
NPKMg	18.8	15.1	15.7	17.3	14.3	14.5	9.9	15.1
NPSMg	19.7	22.5	16.0	16.0	12.6	14.5	13.3	16.4
NKSMg	19.0	13.3	15.1	14.5	13.9	14.6	14.2	14.9
PKSMg	24.1	16.3	15.9	12.6	12.5	11.9	10.9	14.9
Soil type mean	21.1	17.4	16.8	15.9	14.4	13.6	12.0	15.9

[a]Soil type: SE = ± 0.82; LSD 5% = 2.45; fertilizer: SE = ± 0.72; LSD 5% = 2.00; fertilizer treatment within soil type: SE = ± 1.89; LSD 5% = 5.3.

MATERIALS AND METHODS

The list of soil samples used in the experiment is given in Table 1. Soil texture was measured by the hydrometer method; a 1 : 1 soil : water ratio was used in pH measurements with glass electrode; organic carbon was determined by a modified version of the Allison wet digestion method; total nitrogen was determined by the Kjeldahl method; extractable phosphorus was determined with a Bray no. 1 extractant; exchangeable cations were extracted by 1 N ammonium acetate; and extractable zinc was measured after extraction with 0.1 N hydrochloric acid.

Plant samples were digested in a Tecator model 40 aluminum digestion block; the reagents were nitric, perchloric, and hydrochloric acids. Phosphorus was measured by means of a Technicon

autoanalyzer; potassium, by means of an EEC flame photometer; and zinc, with a Perkin Elmer model 403 atomic absorption spectrophotometer. Nitrogen was measured by a micro-Kjeldahl distillation method.

The greenhouse trial was a split-plot design with four replications. The seven soil types constituted the main plots; five fertilizer treatments were applied to subplots: NPKSMg, NPKS, NPKMg, NPSMg, NKSMg, PKSMg, and control (no fertilizer). N, P, and K were added at 100 ppm each and Zn and S added at 20 ppm each. Five kilograms of air-dried soil was used in each pot. Fertilizers were thoroughly mixed with soil, and the pots watered to field capacity. Four stakes of cassava variety TMS 30395 were planted in each pot and thinned after 2 weeks to two plants/pot. A top dressing with 25 ppm N was made at 5 WAP (weeks after planting). Plants were harvested at 12 WAP. Index leaf samples were collected at 8 WAP for Zn determination.

RESULTS AND DISCUSSION

SOIL ANALYSIS

Some of the characteristics of the soils used in the study are shown in Table 2. Except for the Araromi soil, which was sandy clay loam, all the soils were coarse, ranging from loamy sand to sandy loam. The Araromi soil, which is derived from amphibolitic rocks, showed the highest nutrient status; the Onne soil, which is derived from marine sediments, exhibited the lowest. Except for the Onne soil, the soils were low in extractable P; the soils derived from sandy sedimentary materials (Ikenne, Nkpologu, and Onne) were also low in exchangeable K. Also noteworthy is the high acid-

Table 5. N, P, K concentrations (%) in index leaf blade as affected by fertilizer and soil type (12 WAP).

	Egbeda	Alagba	Apomu	Shante	Nkpologu	Onne	Araromi	Fertilizer mean
				N(%)				
Control	4.5	3.5	3.9	3.2	3.1	4.4	6.0	4.1
NPKSMg	5.0	4.2	5.4	4.4	4.9	5.3	5.5	5.0
NPKS	5.2	3.8	5.2	4.9	3.4	6.4	5.9	5.0
NPKMg	5.0	3.8	5.2	5.1	4.5	5.6	5.5	5.0
NPSMg	5.2	4.0	5.0	4.6	3.6	5.3	5.7	4.0
NKSMg	5.8	3.9	3.3	4.5	3.4	6.0	5.1	4.6
PKSMg	4.5	3.6	4.5	3.4	3.1	4.9	5.0	4.1
Soil mean	5.0	3.8	4.6	3.8	3.7	5.4	5.5	
				P(%)				
Control	0.14	0.22	0.18	0.25	0.15	0.16	0.17	0.18
NPKSMg	0.30	0.28	0.20	0.32	0.24	0.23	0.20	0.25
NPKS	0.20	0.13	0.30	0.32	0.22	0.24	0.22	0.23
NPKMg	0.23	0.22	0.32	0.32	0.16	0.24	0.21	0.24
NPSMg	0.30	0.20	0.31	0.26	0.24	0.30	0.34	0.28
NKSMg	0.16	0.18	0.19	0.18	0.18	0.16	0.13	0.17
PKSMg	0.32	0.30	0.30	0.39	0.23	0.21	0.28	0.29
Soil mean	0.24	0.22	0.26	0.29	0.20	0.22	0.22	
				K(%)				
Control	2.60	1.10	1.30	1.64	1.30	1.33	2.94	1.74
NPKSMg	2.90	1.39	2.63	3.15	1.50	2.00	3.10	2.38
NPKS	2.90	0.85	2.60	2.46	1.54	3.10	2.60	2.29
NPKMg	2.90	1.30	2.50	2.46	2.86	2.45	2.60	2.44
NPSMg	2.11	0.75	1.77	1.10	1.12	1.35	2.20	1.49
NKSMg	2.97	2.17	2.10	2.33	1.51	2.01	2.90	2.28
PKSMg	1.40	1.41	1.26	1.77	1.60	2.49	2.79	1.82
Soil mean	2.54	1.28	2.03	2.13	1.63	2.10	2.73	

Table 6. Zn levels (ppm) in cassava leaf blades at 8 and 12 WAP.

Fertilizer treatment	Egbeda		Alagba		Apomu		Shante		Nkpologu		Onne		Araromi	
	8 WAP	12 WAP	8 WAP	12 WAP	8 WAP	12 WAP	8 WAP	12 WAP	8 WAP	12 WAP	8 WAP	12 WAP	8 WAP	12 WAP
Control	27	62	20	31	23	62	24	54	29	56	30	54	33	64
NPKSMg	32	40	27	38	32	39	18	16	30	32	41	44	41	55
NPKS	35	44	23	40	29	38	20	43	26	29	32	44	32	44
NPKMg	38	32	26	37	39	43	21	22	26	69	38	42	38	45
NPSMg	29	31	29	43	27	54	21	35	24	64	36	39	36	30
NKSMg	39	56	23	44	36	61	26	48	26	67	33	44	33	60
PKSMg	27	38	23	33	23	55	24	57	20	59	34	41	35	49
Mean	32	43	24	38	30	50	22	39	22	54	35	44	35	50

ity of the Onne and Nkpologu soils. In another study, the Onne soil was shown to have high levels of extractable aluminum.

PLANT GROWTH

Plant height, as measured at 5 WAP, varied significantly with soil types (Table 3). The mean plant height was very much affected by soil type. Though there were no significant differences attributable to fertilizer treatment, best growth was observed with complete treatment (NPKSMg).

The plant dry weight determined at 12 WAP probably gives a better indication of the productivity of the soil than does the height of plants (Table 4). The mean dry weight was also very much affected by soil type. The Araromi soil, which had the highest nutrient status, gave the highest dry weight. Yields from control treatments were lower than those from soils that had a complete fertilizer mixture. The treatments without nitrogen and phosphorus gave the lowest yields, averaged over all soils.

A comparison of the effects of fertilizer treatments on the various soils indicates that the plants responded to nitrogen treatment on Alagba, Onne, Nkpologu, and Shante soils; to phosphorus on Araromi, Egbeda, Apomu, and Alagba soils; to potassium on Araromi, Apomu, Alagba, and Onne soils. Also, dry-matter yield increases were observed with sulfur addition on all soils, but particularly on Apomu and Shante soils, and magnesium application significantly increased dry-matter yield from the Shante soil.

PLANT NUTRIENT STATUS

The index leaf blades taken at 12 WAP indicated that the Araromi soil sustained plants with the highest nitrogen status; the amount ranged from 5 to 6% and was not appreciably affected by fertilizer treatment (Table 5). Plants on other soils showed marked increases in leaf nitrogen levels with N addition, although the levels in plants on the Alagba, Shante, and Nkpologu soils were still below the critical N level indicated by Howeler (1978). This may mean that application rates of 125 ppm N are not sufficient for these soils.

Plants grown on all soils showed marked responses in leaf blade phosphorus with P application. In general the blade levels without P application were lower than the 0.2% critical value reported by Howeler (1978).

Potassium was highest in leaves from plants on Egbeda and Araromi soils and lowest for plants on Alagba, Nkpologu, and Onne soils, which showed good responses to K application.

Low zinc levels were observed in leaf blades at 8 WAP (Table 6). Zinc deficiency symptoms were observed on plants grown on Alagba, Nkpologu, and Shante soils. The levels in plants showing deficiency symptoms ranged from 18 ppm to 27 ppm, which are below the critical level of 35 ppm reported by Howeler (1978). Levels improved substantially by the 12th week without any Zn addition, and the deficiency symptoms were scarcely discernible.

The data clearly showed some relationship between soils, crop growth, and plant nutrient status. It also appears that soils derived from basement complex rocks in the forest zone (Araromi, Egbeda, and Apomu series) have higher potential for cassava production than those derived from sandy sedimentary rocks (Alagba, Onne, and Nkpologu series) or sandy soil from derived savanna (Shante series).

The nitrogen responses in the Apomu, Shante, Alagba, Onne, and Nkpologu soils (Table 4) were to be expected because of the low N and organic C status of these soils. These responses are a reflection of the vegetative cover (Table 1).

The phosphorus responses observed in this pot trial (Table 4 and 5) may be related to the limited

soil volume used. As indicated by Kang et al. (1980), cassava has low external P requirements, and responses for field-grown cassava are not common.

The sandy entisols (Apomu and Shante) and soils derived from sandy sedimentary rocks (Alagba, Onne, and Nkpologu soils) are potentially more subject to potassium deficiency than are the others. The Shante soil from the derived savanna also showed potential for magnesium and sulfur deficiencies.

Though early zinc deficiency on the Shante and Nkpologu soils was expected because of their low zinc levels (Table 2), it was not expected on the Alagba soil, which had adequate zinc levels. The disappearance of zinc deficiency later (12 WAP) may be related to the ability of the older roots to explore the entire soil volume.

Data from this trial may be useful in the planning of field fertilizer trials in the major cassava-growing areas of southern Nigeria.

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EFFECTS OF SOIL MOISTURE AND BULK DENSITY ON GROWTH AND DEVELOPMENT OF TWO CASSAVA CULTIVARS

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A study of the effects of soil moisture and soil density on cassava yields was undertaken on a well-drained soil derived from fine-grained biotite gneiss and Schist parent materials. Two soil densities and two soil moisture treatments were used. Two cassava varieties were tested — Isunikakiyan and improved 30211. Water use, plant growth, and dry-matter production were evaluated. The findings showed that soil-moisture stress adversely affects shoot and root growth, water consumption, and water use efficiency, although there are varietal differences to drought stress. The adverse effects of soil-moisture stress are accentuated when the plant's root system development is inhibited by high soil bulk density or low total porosity.

Étude des effets de la tension de l'humidité et de la densité du sol sur la production de manioc dans les sols irrigués dérivés de gneiss et schiste à biotite microgrenue. Deux variétés de manioc, Isunikakiyan et la 30211 améliorée ont fait l'objet d'essais dans deux sols de densité différente humidifiés selon deux procédés. L'eau utilisée, la croissance de la plante et la production en matière sèche ont été évaluées. Les résultats ont démontré que la tension de l'humidité a des effets nocifs sur la croissance des racines et des pousses, sur l'efficacité de la consommation et de l'utilisation de l'eau, même si les variétés ne possèdent pas toutes la même tolérance. Les effets nocifs observés sont accentués lorsque le développement du système radiculaire de la plante est retardé par un sol lourd ou à faible porosité.

Although cassava is a relatively drought-tolerant crop that can survive even 4–6 months of dry season, the growth, plant vigour, and yield can be drastically reduced by prolonged periods of drought (Shanmugavelu et al. 1973), and adverse soil conditions may inhibit root development. If the drought stress is slight and of a relatively short duration, cassava can recover from the damage because of its long growth duration.

Among major constraints to cassava production in Africa is the periodic drought stress — a result of a multitude of interacting factors including soil moisture and temperature regimens, root spacing or effective porosity, and methods of seedbed preparation that alter the available soil–water storage capacity. The magnitude of the effects is governed by the amount and distribution of rainfall during the growing season.

Strongly interacting with drought stress is soil temperature, the effects of the two factors often being difficult to separate. The range of optimum root zone temperature is slightly wider for cassava than for the seasonal grain crops such as maize and soybean. Nevertheless, soil temperatures exceeding 35°C in the root zone coupled with low soil moisture availability can result in a significant yield reduction (Okigbo 1979).

The available water-holding capacity of a soil also depends on total porosity and the pore–size distribution. A relatively high proportion of macropores may facilitate water and air movement and provide the much-needed space for the development of tuberous roots. High soil bulk density can significantly decrease the tuberous : feeding root ratio (Vine 1980).

The soil's physical and nutritional properties and the cultural practices can also affect the disease and pest incidence (Hahn et al. 1979). For example, a distinct dry season is necessary for the buildup of the mealybug population.

Although cassava provides more than 50% of the caloric requirements of about 500 million people in the world, this is one of the least-studied crops in terms of its response to a range of soil conditions. The research information concerning the effects of soil conditions on cassava growth and yield is rather scanty. The objective of this investigation, therefore, was to study the effects of soil moisture and soil bulk density on growth and development of cassava.

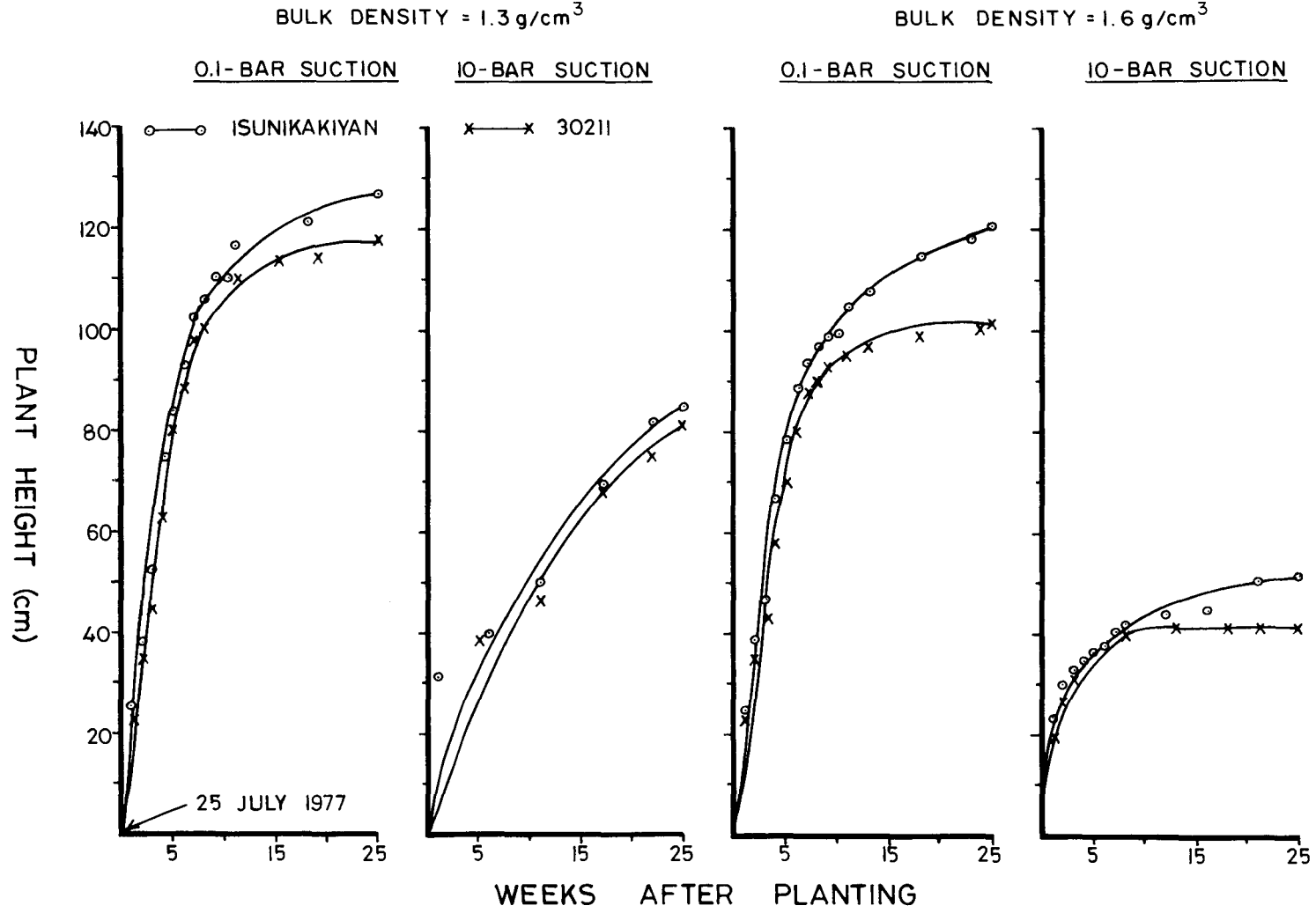

Fig. 1. *Height of two cassava cultivars subjected to different soil treatments.*

MATERIALS AND METHODS

These experiments were conducted in the greenhouse from June 1977 to February 1978. Cassava was grown in wooden boxes 50 × 75 × 100 cm. These boxes were filled with the soil from Egbeda Association. This is a well-drained soil derived from fine-grained biotite gneiss and Schist parent materials (Moormann et al. 1975) and is classified as Tropudalf (Taxonomy) or Ferric Luvisol (FAO). The soil is medium-to-light-textured near the surface, with sandy clay to clay subsoil, and a layer of angular and subangular quartz gravel immediately below the surface. The gravel concentration in the gravelly horizon ranges from 30 to 60%, and the organic carbon content of the surface layer from 0.8 to 1.5%. The clay fraction is dominated by kaolinitic clay minerals and amorphous iron and aluminum oxides.

The available water-holding capacity of the soil is rather low. At series level, the soil is classifed as clayey skeletal, kaolinitic, isohyperthermic, .oxic, paleustalf.

The soil was sampled in the field horizon by horizon and packed in boxes in the same order. The subsoil (5–10 cm depth) was packed at two bulk densities: 1.3 and 1.6 g/cm^3. Soil compaction was done in a way that avoided stratification among successive horizons in the box. There were two soil-moisture treatments. Soil-moisture suction at 15 cm depth was maintained at 0.1 and 10 bars. The regulation of soil moisture suction was facilitated by the use of tensiometers and gypsum blocks, respectively. A 2-cm perforated irrigation tube was installed at the centre of the box and all along its depth. The open lower end of the tube was imbedded in a 5-cm thick layer of coarse gravel placed at the bottom of the box before the soil was packed into it. When necessary, irrigation was done through this tube for uniform distribution of water in the soil body. Each combination of bulk density and soil moisture was replicated three times. Twelve boxes were arranged in the greenhouse according to a complete randomized design.

There were two cassava varieties — a tall and erect local Isunikakiyan and the improved 30211. Two stakes of each variety were planted in each box, totaling four plants per box. Stakes were planted in mid-June 1977, and cassava plants were harvested in February 1978.

Weekly observations were made for plant height and leaf number. Water requirements for two soil-moisture treatments were also computed on a weekly basis. Root and shoot weights were measured at harvest.

RESULTS AND DISCUSSION

WATER USE

Water consumption by cassava was different for different soil moisture and bulk density treatments (Fig. 1). The maximum water use in about 7 months of cassava growth was 24, 63, 90, and 102 cm for 10-bar suction at 1.6 bulk density, 10-bar suction at 1.3 bulk density[1], 0.1-bar suction at 1.3 bulk density, and 0.1-bar suction at 1.6 bulk density treatments, respectively. Water consumption was related to the cassava's growth rate. The water regimen in one of the boxes was altered about 12 weeks after the planting date from 10-bar suction to 0.1-bar suction; the water consumption in that treatment changed drastically.

Under optimum soil-moisture conditions, cassava uses about 4–5 mm of water/day in the first 6 months of its growth. Water consumption under greenhouse conditions may be slightly more than that under natural field conditions. It is expected that water consumption is greater in the later rather than the earlier 6 months of cassava growth because of the time required for a full canopy development and bulking that normally occurs after 10 months of growth. Nevertheless, the cumulative water use for the first 6 months exhibited a linear increase with time without exhibiting any specific periods of high water demand.

PLANT GROWTH

Plant height and growth were affected by soil moisture and bulk density treatments (Fig. 2), although soil moisture had a more pronounced effect than did bulk density. There were no differences in plant height among two bulk densities for the 0.1-bar suction soil moisture treatment. However, plant height at 1.3 bulk density was superior to that at 1.6 bulk density for the 10-bar suction moisture treatment. In general, variety 30211 is shorter than Isunikakiyan. The difference in plant height of the two varieties increased with increase in soil bulk density and soil moisture suction. For example, differences in plant height among the two varieties at 25 weeks after the planting date were 9 and 4 cm for 0.1- and 10-bar suctions at 1.3 g/cm^3 bulk density, and 19 and 11 cm for 0.1- and 10-bar suctions at 1.6 g/cm^3 bulk density, respectively. This differential response implies that variety 30211 is more susceptible to adverse soil-moisture conditions than is Isunikakiyan.

Plant height, in treatments with favourable

[1]Water treatment was altered 12 weeks after planting date.

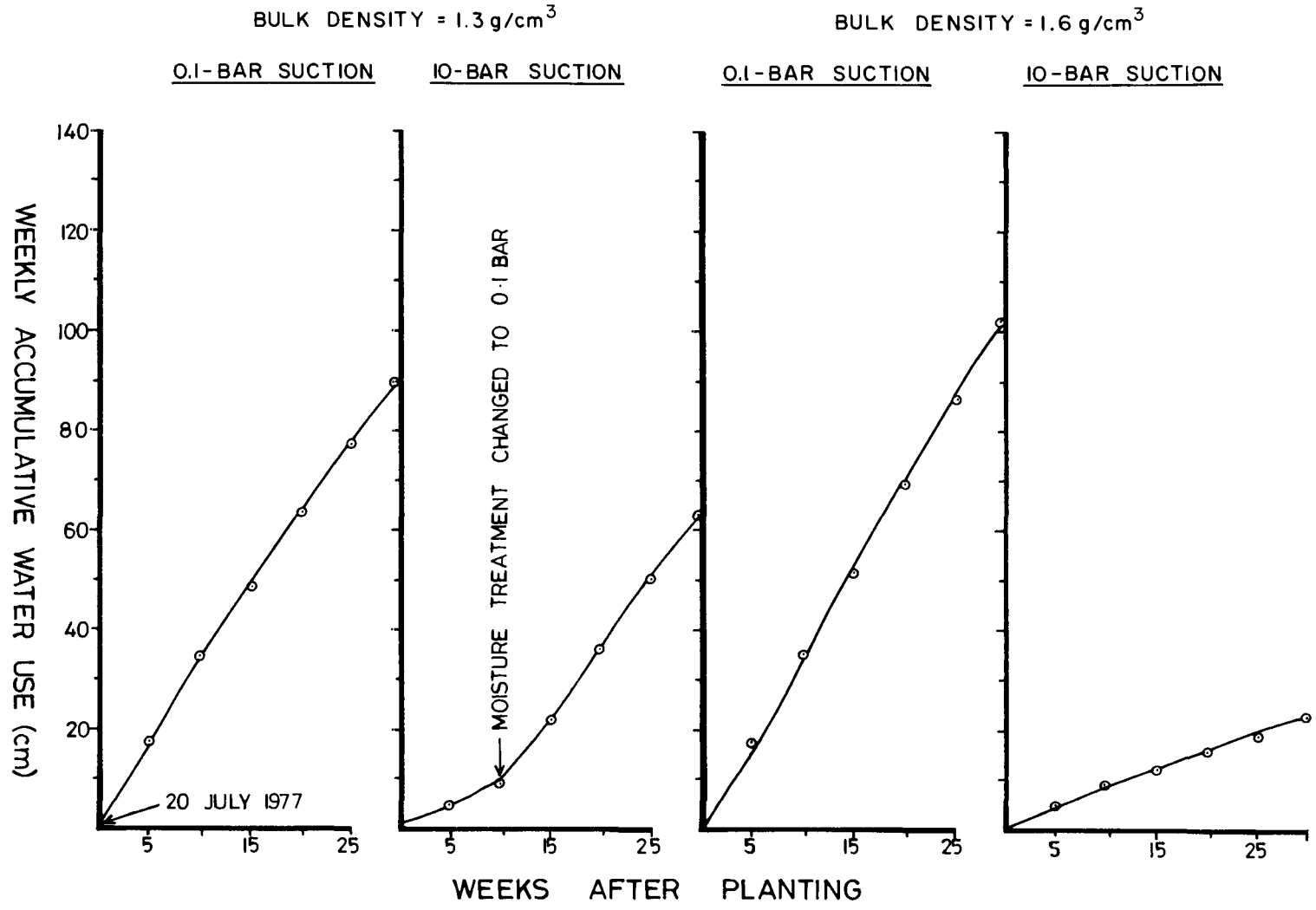

Fig. 2. *Water consumption of two cassava cultivars subjected to moisture stress at two soil densities.*

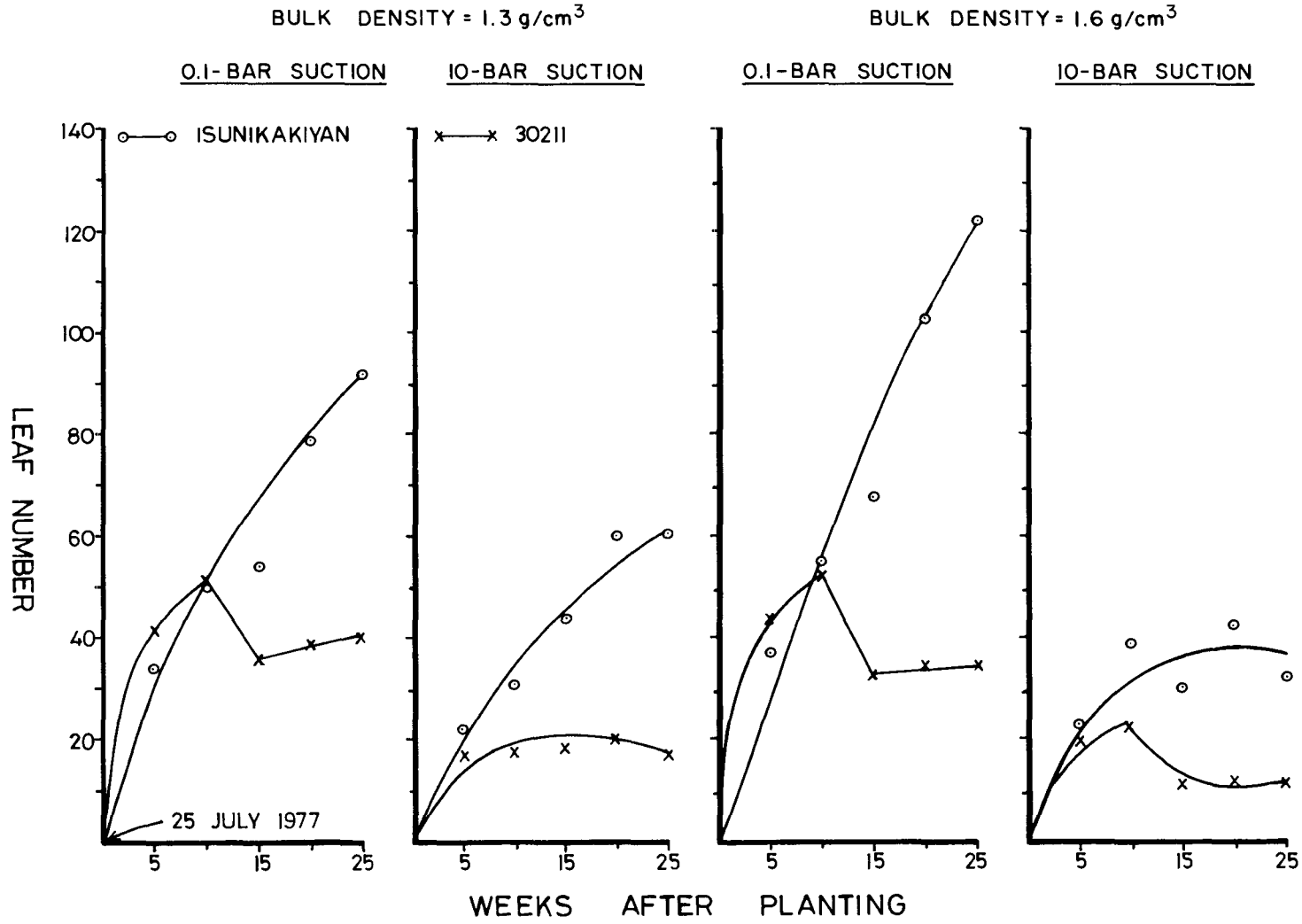

Fig. 3. *Leaf production of two cassava cultivars in different soil treatments.*

moisture, increased rapidly and linearly to about 12 weeks after planting date. Then, lateral branching initiated and rate of vertical increase declined. Once again the maximum plant height of 127 cm was observed for the 0.1-bar suction with 1.3 g/cm^3 soil bulk density, and the least (41 cm) for the 10-bar suction with 1.6 g/cm^3 soil bulk density.

Extreme susceptibility of variety 30211 to adverse soil-moisture conditions is evident from data on leaf numbers (Fig. 3). Isunikakiyan had more leaves than 30211 at all growth stages. Furthermore, variety 30211 dropped its lower leaves about 10–12 weeks after planting. Leaf losses in variety 30211 were observed irrespective of the soil moisture and bulk density treatments.

Leaf numbers in Isunikakiyan were significantly affected by the soil moisture and bulk density treatments. The leaf number at harvest was 102 and 60 for 1.3 g/cm^3 bulk density and 122 and 40 for 1.6 g/cm^3 bulk density for 0.1- and 10-bar suction moisture treatments respectively. The maximum leaf number in 30211 was observed 12 weeks after planting date and was 52 and 20 for 1.3 g/cm^3 bulk density, and 52 and 23 for 1.6 g/cm^3 bulk density for 0.1- and 10-bar suction moisture treatments, respectively. The leaf number at harvest for 30211 was 40 and 18 for 1.3 g/cm^3 density compared with 34 and 11 for 1.6 g/cm^3 bulk density for 0.1- and 10-bar suctions, respectively. For the same moisture regimen, leaf number was adversely affected more at high than at low bulk density. For the same bulk density, the leaf number was adversely affected more at low than at high soil moisture stress (Fig. 3).

Dry-Matter Production

Fresh and dry weights of cassava shoots and roots measured about 26 weeks after planting date were significantly affected by the soil moisture bulk density treatments (Table 1). For example, there was a reduction of 14, 20, 16, and 13% in fresh root weight, dry root weight, fresh shoot weight, and dry shoot weight, respectively, at 1.6 g/cm^3 compared with 1.3 g/cm^3 treatments with 0.1-bar suction. For 10-bar suction, the reduction in growth by increase in bulk density from 1.3 to 1.6 g/cm^3 was 38, 24, 21, and 13% in fresh root weight, dry root weight, fresh shoot weight, and dry shoot weight, respectively.

Data in Table 2 indicate that soil moisture had a far greater effect on cassava growth than did soil bulk density. Percent reduction in growth with increase in suction from 0.1- to 10-bars was 94 and 96 in fresh root weight, 93 and 94 in dry root weight, 61 and 64 in fresh shoot weight, and 65 and 65 in dry shoot weight for 1.3 and 1.6 g/cm^3 soil bulk density, respectively.

The moisture content in roots and shoots was also affected by the soil moisture and bulk density treatments. The moisture content in roots and shoots at 1.3 g/cm^3 bulk density was 212 and 198% at 0.1-bar suction compared with 164 and 230% at 10-bar suction, respectively. Similarly, the moisture content in roots and shoots at 1.6 g/cm^3 bulk density was 236 and 188% at 0.1-bar suction compared with 126 and 199% at 10-bar suction, respectively. Irrespective of the soil bulk density, moisture content in roots declined significantly with increase in soil moisture suction from 0.1 to 10 bars. Furthermore, moisture content in the roots and shoots was generally lower at 1.6 than at 1.3 g/cm^3 bulk density.

Soil moisture and bulk density also affected root : shoot ratio. For example, the fresh and dry root : shoot ratio for 1.3 g/cm^3 bulk density was 1.0 and 0.96, respectively, at 0.1-bar suction compared with 0.15 and 0.19 at 10-bar suction. Similarly, the fresh and dry root : shoot ratio for 1.6 g/cm^3 bulk density was 1.03 and 0.88 for 0.1-bar suction compared with 0.13 and 0.17, respectively, for 10-bar suction. Increase in bulk density also adversely affected root : shoot ratio.

The water use efficiency (WUE), compared as weight per cm of water use, ranged widely among treatments. The water use efficiency for 1.3 g/cm^3

Table 1. Effects of soil moisture and density on shoot and root yields.

	1.3 g/cm^3 bulk density		1.6 g/cm^3 bulk density	
	0.1-bar suction	10-bar suction	0.1-bar suction	10-bar suction
Root				
Fresh weight (g)	1121	66	968	43
Oven-dry weight (g)	359	25	288	19
Shoot				
Fresh weight (g)	1118	433	943	341
Oven-dry weight (g)	375	131	328	114

bulk density was 12.5 and 1.05 for the fresh root weight, 4.0 and 0.4 for the dry root weight, 12.4 and 6.9 for the fresh shoot weight, and 4.2 and 2.1 g/cm for the dry shoot weight for 0.1- and 10-bar suction soil moisture regimens, respectively. The water use efficiency for the 1.6 g/cm^3 treatments, at 0.1- and 10-bar suctions respectively, was 9.2 and 2.0 for the fresh root weight, 2.8 and 0.9 for the dry root weight, 10.5 and 15.5 for the fresh shoot weight, and 3.2 and 5.2 g/cm for the dry shoot weight. Increase in bulk density decreased the fresh weight WUE, whereas the reverse was the case with the dry weight WUE. The WUE, however, decreased drastically with an increase in soil water suction from 0.1 to 10 bars.

Under the present experimental setup, it was difficult to evaluate the varietal response to soil-moisture deficit in terms of dry-matter production.

Soil-moisture stress can adversely affect shoot and root growth, water consumption and, water use efficiency. There are varietal differences to drought stress. Plant height, vigour and, secondary branching of cassava are also affected by soil moisture. At high moisture stress, the moisture content in the roots is decreased more drastically than is that in the shoots. The adverse effects of soil-moisture stress are accentuated when the plant's root system development is inhibited by high soil bulk density or low total porosity.

There is a need to investigate plant–water requirement of cassava in relation to different cultural practices. The effects of soil moisture on cassava should be evaluated in terms of plant–water potential. The high yield potential of cassava can be realized with proper soil, water, and nutritional management.

PERFORMANCE OF CASSAVA IN RELATION TO TIME OF PLANTING AND HARVESTING

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Growth and yield of cassava at different times of planting and harvesting were studied in replicated trials at Nsukka, Nigeria. In the first experiment, cassava planted on 14 September 1973 was harvested at fortnightly intervals beginning at 9 months until 13 months after planting. Yields of stakes and commercial roots showed significant increases up to the eighth harvesting at about 12 months and declined thereafter. In the second experiment, planting was done every fortnight beginning 6 June and ending 9 October, 1974. A third experiment investigated the period 13 August–15 October in weekly plantings. All the plants of the second and third experiments were harvested at 12 months after planting and the yields of roots, stems, stump (old stalk), and number of leaves at harvest were compared. The highest weight of roots was obtained from the June, late July to early September plantings, and the number of roots followed similar trends. Stump weights were highest from the June and late August to September plantings. The reduction in number of roots was not significant. Significantly higher dry-matter yields were obtained from the September plantings — a finding that suggests the best time to plant cassava is during the late rather than the early cropping season. The results are discussed in relation to ambient weather conditions during the experimental period.

Essais comparés effectués à Nsukka, 6°52″ de lat.N sur la croissance du manioc et son rendement planté et récolté à différentes dates. Pour la première expérience, du manioc planté le 14 septembre 1973 a été récolté de 9 à 13 mois plus tard à des intervalles de 15 jours. Les rendements en tiges et racines commerciales ont progressé jusqu'à la huitième récolte, soit à peu près 12 mois après la plantation pour décliner par la suite. Pour la seconde expérience, le manioc a été planté tous les quinze jours du 6 juin au 9 octobre 1974. Une troisième expérience portait sur les plantations effectuées toutes les semaines du 13 août au 15 octobre. Dans les deux derniers cas, les récoltes ont été effectuées 12 mois après la plantation et les racines, le tronc, les souches et les tiges ainsi que le nombre de feuilles au moment de la récolte ont été comparés. Le plus grand nombre de racines et les plus gros tubercules provenaient des semis effectués en juin, fin juillet et début septembre. Et ce sont les plantations faites en juin, fin août et septembre qui ont donné les souches les plus considérables mais le nombre de racines était à peu près égal au précédent. Le rendement en matières sèches a été considérablement plus élevé chez les plantes semées en septembre, ce qui permet d'avancer que la période optimale de plantations se situe à la fin plutôt qu'au début de la saison de culture. Les résultats sont étudiés par rapport aux conditions atmosphériques prévalant au moment de l'expérience.

The time of planting or harvesting cassava is not usually considered critical on upland areas where groundwater does not present root-rot problems. However, where cassava is allowed to remain in the soil for too long, it may interfere with effective use of land for intensive crop production. This problem is particularly important in areas of high population density like in parts of southeastern Nigeria.

In a cropping sequence in which cassava is followed by another rainfed crop without an intervening fallow, the time of planting and harvesting should be adjusted to accommodate the following crop during the conventional growing season. Cassava can grow through the dry season without necessarily requiring irrigation. Additionally, cassava can be planted at almost any time during the growing season between March and October with equally successful establishment. However, some reports suggest that cassava planted during the long days between May and July tends to yield less than it does at other planting dates. The Centro Internacional de Agricultura Tropical (CIAT 1974) reported that the highest yields of fresh roots were recorded in April–July plantings, but the percentage starch was lowest in the April planting and increased steadily until the November–January plantings. The plantings in November–February were irrigated. Usually, farmers interplant cassava during the later part of the rainy season because the closed canopy from it suppresses the growth of other crops or because farmers are least pressed during this time by other operations on the farm

(Okigbo 1971). However, the increasing interest in cassava as a convenient farm crop has initiated a shift in the planting date from the second to the first half of the cropping season, with some plantings as early as March or April.

In a series of three-weekly plantings between 23 April and 29 October at Nsukka, Nigeria, Okigbo (1971) observed no significant correlation between yields of storage roots and time of planting. Higher yields of storage roots were obtained from plantings between 27 August and 8 October than from early or midseason plantings between 23 April and 25 June. He attributed the lower yields obtained from the early through midseason plantings to defective bulking due to long days that prevailed during the first 3 months after planting. Day lengths greater than 12 h have been shown to reduce root bulking in cassava (Bolhuis 1966; Mogilner et al. 1967; CIAT 1972, 1973) and the duration of day length at Nsukka, excluding civil twilight hours, is usually greater than 12 h between April and August.

Beck (1960) noted that, in cassava, all storage roots are formed within 6 months, and subsequent increases in yield derive from accumulation of dry matter in the roots. CIAT (1973) indicated that the number of cassava roots with capacity to thicken (storage roots) is fixed within the first 3 months and that increases in root dry matter proceed rapidly up to 8 months after planting and thereafter slowly for the rest of the growth period. Balakrishnan and Sundararaj (1967) concluded that the best time to harvest cassava was between 12 and 12.5 months after planting and that roots harvested earlier or later than this were inferior in quality. Thus, the best combination of quantity and quality yields may be expected at about 12 months after planting. CIAT (1973) further indicated that harvest index increased up to 8 months after planting and thereafter remained constant — a fact suggesting that root and stem growth proceed at the same rate.

If the number of storage roots is fixed within the first 3 months, the yield of cassava probably depends more upon the extent of assimilation and assimilate accumulation in these roots than on numbers of roots. Assimilation, in turn, depends, among other things, on the extent of the assimilating surface and the amount of isolation.

This paper reports the results of further experiments on the performance of cassava in late-season cropping. The objective of the experiments was to rationalize the planting sequence in the intensively farmed areas of southeastern Nigeria.

MATERIALS AND METHODS

We conducted three experiments at Nsukka, Nigeria, to determine the optimum times of harvesting and planting and to evaluate the effects of different times on the yield and the general performance of cassava.

In the first experiment, 22.5-cm cassava stakes of the cultivar Congo (Panya 48086) were planted 1 m apart along ridges 1 m apart on 14 September 1973. We constructed cross ridges to check runoff. The experimental design was a randomized complete block with four replications, in which 10 fortnightly harvesting intervals were located at random within each replicate. Each plot measured 6 × 10 m. Routine weeding operations and general cultural maintenance were carried out as necessary. NPK fertilizer (15:15:15) was applied at the rate of 450 kg/ha at 1 month after planting. There were 10 fortnightly harvests from the 9th through the 13th month after planting. The sample size was 20 stands per plot taken from the four inner rows 4 × 5 m.

In a second experiment, 10 fortnightly planting dates from 6 June through 9 October 1974 were investigated in a randomized complete block design with four replications. Plot size and cultural treatments were similar to those in the first experiment,

Table 1. Yields of old stalk and storage roots of cassava planted 14 September 1973 in relation to time of harvesting.

Yield	Age at harvesting (months after planting)										Standard error (±)[a]
	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	
Dry wt. of old stalk (t/ha)	1.08	1.05	1.25	1.53	1.50	1.59	1.73	1.76	1.62	1.66	0.13*
Dry weight of storage roots (t/ha)	2.41	2.89	3.69	4.88	5.53	5.65	7.42	7.34	6.90	6.92	0.81*
Dry matter (%) content of roots	31.3	31.6	32.3	32.6	39.8	41.2	39.6	42.2	44.9	41.3	2.25**

* = significant at 5% level of probability; ** = significant at 1% level.

Table 2. Effects of time of planting on the yield of cassava harvested at 12 months after planting.

Mean	Dated planted										Standard error (±)[a]
	June 6	June 19	July 3	July 17	July 31	Aug 14	Aug 28	Sept 11	Sept 25	Oct 9	
Height of plants (m)	2.25	2.04	1.83	1.08	2.06	2.08	2.24	2.16	1.92	1.99	0.08*
Stems/plot	35	34	35	34	31	33	29	26	22	22	1.98**
Stems/plant	1.8	1.7	1.8	1.7	1.5	1.7	1.5	1.3	1.1	1.1	0.99**
Leaves/plant	75	71	74	106	89	111	118	115	89	87	9.64**
Stems (kg/plot)	14.5	12.5	12.2	11.8	11.1	11.3	11.0	10.3	6.3	5.4	1.15***
Stems (t/ha)	7.2	6.3	6.1	5.9	5.6	5.7	5.5	5.2	3.2	2.7	0.5***
Old stalks (kg/plot)	2.3	2.0	1.8	2.1	1.7	1.6	1.9	1.8	1.3	1.4	0.14***
Old stalks (t/ha)	1.2	1.0	0.9	1.1	0.9	0.8	1.0	0.9	0.7	0.7	0.07***
Roots/plot	175	187	191	222	170	198	180	209	129	146	10.80***
Storage roots/plot	67	60	36	55	39	43	56	65	31	44	3.56**
Storage roots (t/ha)	16.3	15.8	11.6	14.9	14.2	14.0	15.5	16.5	14.4	10.5	1.33 NS
Dry weight storage roots (t/ha)	4.4	6.0	6.2	7.2	7.3	8.1	7.5	9.2	7.7	5.9	0.98*
Top–root ratio	1.27	1.00	1.14	1.15	1.11	1.14	1.18	0.88	0.67	0.80	NA

[a]NS = not significant; * = significant at 5% level of probability; ** = significant at 1% level; *** = significant at 0.1% level; NA = not analyzed statistically.

and harvesting was done at 12 months after planting. Number and fresh weight of roots; height, weight, and number of stems; and weight of stumps (old stalk) were recorded for each plant at harvest. We used a 10% sample of each plot's harvest to determine the dry weight of roots and stems separately.

In a third experiment, the late cropping season from mid-August to mid-October 1975 was investigated more closely at weekly plantings. The same experimental design, plot size, and cultural practices were maintained, and each planting was harvested 12 months later. The same set of observations were taken as in the second experiment.

All the data collected were analyzed statistically, and some of these were related to parameters of the weather at certain periods of growth of the crops.

RESULTS AND DISCUSSION

The yield of storage roots increased steadily up to the 12th month and, thereafter, leveled off (Table 1). Similar increases were also observed in the old stalks, which, like the storage roots, attained the highest values at about 12 months. This finding suggests that stumps can provide alternative sink for assimilates up to 12 months after planting. Although the dry weight of the storage roots increased rapidly between the 11th and 12th months after planting, there was no further increase subsequently. Thus, the best time to harvest cassava appears to be between 11 and 12 months after planting. Balakrishnan and Sundararaj (1967) indicated that cassava harvested before or after 12–12.5 months after planting tended to be inferior in quality. However, we did not investigate the quality aspects of cassava yield.

Although cassava could be left in the soil and harvested as required, it would appear that once-over harvesting at about 12 months would be ideal in situations where the roots are required for processing.

Earlier results from time-of-planting studies at Nsukka (Okigbo 1971) showed that cassava planted later than June produced higher yields of storage roots than did that from earlier plantings. In our study, June–October was investigated in greater detail through fortnightly plantings beginning 6 June and ending 9 October 1974 (Table 2).

The yields of fresh storage roots did not differ significantly for any of the planting dates. The dry-matter yields, however, did, being highest from the 11 September planting and least from the 6 June planting. The average dry-matter yield for the months was lowest in June (4.4 t), increased steadily through July (6.9 t) and August (7.8 t), peaked in September (8.5 t), and declined in October (5.9 t). These results agree with earlier reports (CIAT 1974) that, although high fresh root yields may be obtained from early plantings (April–June), the dry matter and starch contents are lowest from April plantings but increase steadily until November–February when the dry-season plantings were irrigated. In our study, where no

Table 3. Observations on yields of cassava planted at weekly intervals during the late cropping season.[a]

	Roots (total/ plot)	Roots (kg/ plot)	Commercial roots (total/ plot)	Commercial roots (% of total weight)	Commercial roots (kg/root)	Commercial roots (% dry matter)	Old stalk (kg/ plot)
13 Aug	506	38.1	104	82.0	0.29	33	4.8
20 Aug	505	33.4	93	78.7	0.31	34	4.5
27 Aug	444	38.9	99	98.5	0.39	33	4.2
3 Sep	417	38.6	97	95.4	0.38	37	4.2
10 Sep	379	44.1	101	96.1	0.42	39	4.6
17 Sep	384	46.3	109	95.1	0.39	40	4.3
24 Sep	405	41.3	102	96.2	0.39	36	4.3
2 Oct	438	40.6	92	95.7	0.43	37	3.3
8 Oct	425	32.3	79	94.5	0.39	36	3.2
15 Oct	413	31.8	80	93.4	0.38	40	3.9
SE±	49.01	4.83	8.20*	3.46**	0.03**	6.77	1.44

[a] * = significant at 5% level; ** = significant at 1% level.

irrigation was used, the yield declined in October — an indication that water shortage curtails dry-matter accumulation.

The number and fresh weight of stems were highest in June and July and least in late September and October plantings. Similarly, the weight of old stalks tended to decrease from June to October plantings, whereas more foliage was retained by crops planted from July to October than by those planted in June. Whereas September and early October plantings had top : root ratios of 0.78 and 0.80, respectively, the ratios for June, July, and August were 1.13, 1.13, and 1.16. Similarly, the harvest indices were higher in September (57%) and October (56%) and lower in August (46%) and June–July (47%). The results further suggest that planting in June and July tends to produce high yields of skeletal tissues, particularly stumps, at the expense of root bulking.

Although yields of storage roots were positively and significantly correlated with yields of stems ($r=0.6914$) and stumps ($r=0.6896$), the low values of these correlations support the view that excessive growth and development of stems and stumps may severely limit the bulking of storage roots. Coupled with the higher top : root ratios observed in June and July plantings, the results of this study confirm earlier reports (Okigbo 1971; CIAT 1974) that it is preferable to plant cassava later than June, preferably, in September. Planting in September permits an early crop to be harvested or otherwise attain maturity before the cassava is introduced in a relay planting or modified mixed cropping.

The dry weight of roots was positively and significantly correlated with insolation received by the crop between 3 and 9 months ($r=0.6373$), although a stronger influence appeared to exist between 3 and 6 months ($r=0.7554$) than at other 3-monthly periods. The negative relationship observed at 9–12 months ($r=-0.4742$) suggests that during that period cassava does not actively bulk further reserves in the roots and may in fact be drawing on the root reserves to maintain the well-developed stems and other skeletal tissues.

There was a small positive correlation ($r=0.2844$) between rainfall received at 0–3 months and final dry-weight yields of storage roots. This could be attributed to the effect of moisture on survival and early establishment of stakes. A similar relationship at 6–9 months ($r=0.1456$) could be ascribed to the needs of the crop for active bulking of the roots at this stage. During the earlier 3-month periods, when the crop was in active vegetative

Table 4. Sperman's coefficient of rank correlation between yields and some yield components.

Component	Rank correlation (r_s)[a]	t
Yield of commercial roots vs total roots recovered	−0.6363*	2.335
Yield of commercial roots vs number of commercial roots	+0.7484**	3.374
Average weight of commercial roots vs total roots recovered	−0.3576 NS	1.180
Yield of commercial roots vs percentage dry weight of commercial roots	+0.3697 NS	1.105

[a] NS = not significant; * = significant at 5% level of probability; ** = significant at 1% level.

growth, rainfall tended to be negatively correlated with dry weight of roots. These findings suggest that cassava is not a moisture-loving crop but will require moderate amounts of rainfall during most stages of its growth, particularly during the periods when it is storing starch in the roots and is rapidly bulking. CIAT (1973) reported that the rate of dry-matter accumulation in the storage roots was rapid between 3 and 8 months and, thereafter, proceeded at reduced rates until harvest. This suggests that limitations to yield are most pronounced when growing conditions with respect to rainfall and insolation are poor during this stage of development.

The late cropping season, though generally conducive to high yields of cassava, nevertheless exhibited small variations that, in some instances, resulted in significant differences in the performance of the crop (Table 3).

An analysis of ranked observations clearly indicated that the best time to plant cassava lies between the last week of August and the first week of October.

Our results (Table 4) showed that weight and number of commercial roots are positively and significantly related, but the relationship with total roots is negative and significant also. Similarly, the average weight of commercial roots is negatively, but not significantly, correlated with total roots produced.

These results showed that, although early-season plantings encourage vigorous growth, the effective yields of the crop are usually lower than in late-season plantings. Thus, there is very little advantage in extra-early planting of cassava in the Nsukka area. It is, however, relevant that farmers in this area usually plant cassava as a late crop, and, in some instances, planting is continued until early November. Cassava requires some moisture to establish properly, and the late rains in September and October usually provide sufficient moisture for its establishment.

THE EFFECTS OF PREVIOUS CROPPING ON YIELDS OF YAM, CASSAVA, AND MAIZE

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In a 4-year continuous cropping trial, 21 treatment sequences of cassava, yam, and maize as sole crops were evaluated for the effects on the yield of each of the crops and the total caloric yield. The plots received annual supplements of N, P, K, and compost. Yield differences among the sequences were significant with respect to the crops. Best yields of yam, after 4 years, were obtained from plots where yam followed 3 years of maize or cassava, whereas worst yields were obtained from plots where yam followed the "basic" rotation (recommended by the Ministry of Agriculture), which is yam followed by maize and, then, cassava. Highest yields of cassava in the fourth year were recorded when cassava followed maize followed by (fb) yam, fb maize. As in yams, worst yields were recorded for cassava following the basic rotation.

Nematode populations in the yam plots and incidence of nematode attack were not influenced by the sequence. Total caloric yields during the 4 years were highest when root crops dominated the sequence. Annual relative mean yields of yam, cassava, and maize showed a steady decline with continuous cropping. It is concluded that the basic rotation of yam fb maize fb cassava is inferior to other sequences in maintaining soil fertility and sustaining high yields. Yields cannot be sustained and fertility maintained under the heavy rainfall typical of the area, even through the use of organic manures and fertilizers.

Rapport des 4 années d'essais comprenant 21 séries de cultures d'assolement associant l'igname, le manioc et le maïs en vue d'apprécier les effets de chaque culture sur la suivante et le rendement calorique total. Les champs ont été amendés chaque année avec N, P, K et du compost. Les rendements des séries de culture ont été très variés. Pour la quatrième année, la production d'ignames a été la plus élevée lorsqu'elle suivait 3 années de culture de maïs ou de manioc alors que la plus faible a été obtenue sur des parcelles où l'igname suivait la succession recommandée par le Ministère de l'Agriculture, soit igname + maïs + manioc. Les rendements de manioc les plus élevés à la fin de l'expérience ont été enregistrés lorsqu'ils venaient à la suite du maïs, suivi par l'igname et encore le maïs. Comme dans les cas précédents, les rendements les plus faibles ont été obtenus en suivant la séquence recommandée.

L'ordre de la séquence n'a eu aucun effet sur l'apparition des nématodes et leur population dans les champs d'ignames. Les rendements en calories ont été les plus élevés au cours des quatre années lorsque les plantes-racines étaient en tête d'assolement. Les moyennes annuelles relatives de l'igname, du manioc et du maïs ont baissé régulièrement en culture continue. En conclusion, la rotation recommandée, ignames + maïs + manioc, est inférieure aux autres séquences pour le maintien de la fertilité du sol et d'une production élevée. Les rendements ne peuvent être soutenus non plus que la fertilité du sol maintenue dans ces régions à forte précipitation, quel que soit l'apport d'engrais ou de fertilisants.

Guesstimates are that by the year 2000, the population of Nigeria will double to 145 million (IADS 1980). At an annual growth rate of 3.2%, about 1.9 million additional people will need to be adequately fed every year. To cope with this expected increase in population and to avert the nightmares predicted by the Malthusian postulate, it is mandatory that agricultural production be increased.

The federal government of Nigeria has already taken a step in the right direction by instituting its laudable Green Revolution program and its predecessor, Operation Feed the Nation. Making the Green Revolution a reality would require the opening up of more agricultural lands or increasing the productivity of the present lands. In the face of the rapid pace of urbanization and industrialization, both of which must compete with agricultural production for the available land, the former alternative seems the less attractive.

Hitherto, the system of agriculture variously described as shifting cultivation (Ruthenberg 1976), land rotation cultivation, recurrent cultivation (Allan 1965), rotation bush-fallow (Faulkner and Mackie 1933; Obi and Tuley 1973), and shifting field agriculture (Morgan 1969) has been

the chief means of increasing productivity. The length of the fallow or the resting period has been dependent upon the pressure on the land and the fertility of the soil as indicated by crop yields. But with the introduction of the cash crop economy and the rapid increase in population, this system is becoming too much of a luxury, its obvious advantages of soil fertility restoration, soil conservation, and control of pests and diseases notwithstanding. Finding alternatives to the system is on the priority list of many a national program. All alternatives have as their theme the shortening and, if possible, total elimination of the fallow period (FAO 1966, 1974; Herman 1969). The theme presumes that the soil fertility and productivity can be sustained by other means, such as the use of improved agricultural packages (including the use of fertilizers and manures). This presumption is still to be fully tested.

The continuous cropping experiment reported in this paper was designed to investigate the possibility of maintenance of the soil fertility in a heavy-rainfall forest zone of southern Nigeria under a system of continuous intensive cropping through the use of organic manures and fertilizers. A second objective was to determine the yield potential of the crops under a system of continuous cropping dominated by yams, cassava, and maize.

METHODS AND MATERIALS

The experiment as originally planned was sited on a deep porous yellowish brown sandy clay loam soil at Umudike, which has annual rainfall of 2125 mm. This is one of the dominant soils of Imo State.

The cropping system in this region is dominated by the basic food crops, yam, cassava, and maize. This system has been described for the oil-palm belt of eastern Nigeria in general (Obi and Tuley 1973) and for Umokile and Owerri, in particular (Ruthenberg 1976). Findings from a cropping system survey (NRCRI 1977) in the region indicated that commonly in the first year yam is intercropped with early maize and vegetables and interplanted with cassava; in the second year, cassava is planted and is followed by *Acica bartari* or, more recently, *Eupatorium odoratum* bush fallow; and in the third to the sixth years bush fallow is continuous. Thus 1.5–2 years of normal cropping is followed by 4–7 years of fallow.

In our study, the yields from three major crops yam, maize, and cassava were compared after continuous cultivation in different combinations of rotation. Spacings for the yam (*Dioscorea rotundata*, Obiaoturugo variety), cassava (Nwugo variety) and maize (N.S-1) were 120 cm, 120 cm, and 30 cm, respectively, along 100-cm ridges. Gross and net plot sizes were 0.01 and 0.0067 ha, in that order. Each plot received a blanket application of 336 kg/ha of 10–10–20 NPK fertilizer and 25 t/ha of compost.

The experiment was laid out in a randomized complete block design (RCBD) in four replicates — a total of 84 plots. So that all possible combinations of rotation could be tested, it was scheduled to run from 1976 to 1987; however, because of financial constraints, it had to be terminated in 1979, hence the unbalanced nature of the treatments reported. For the statistical analysis, all the treatment phases that carried the same sequence of crops in 1976–79 were grouped as one treatment. The experiment was thus analyzed as a RCBD with unequal sample sizes as for treatment means adjusted for covariance (Bancroft 1968).

Data collected were yield of fresh yam tubers, cassava roots, and maize grains; nematode populations 2 weeks before harvest (number/250 g soil); and percent of tubers damaged. Total energy yield per treatment was calculated as 381, 409, and 391

Table 1. Total productivity over the 4 years as influenced by the cropping sequence.[a]

Sequence[b]				Energy yield
1976	1977	1978	1979	(cal × 10^7/ha)
Y	Y	Y	Y	19.48
C	Y	M	C	18.97
Y	Y	M	C	18.66
C	Y	M	C	17.43
C	C	C	Y	17.28
C	Y	Y	Y	17.06
C	C	C	C	16.22
Y	M	C	Y	16.21
Y	Y	Y	M	14.84
Y	M	C	Y	14.57
Y	M	C	C	13.50
M	Y	M	C	12.83
C	C	Y	M	12.66
M	C	C	C	11.70
Y	M	C	M	11.31
M	C	Y	Y	10.72
C	M	M	M	7.94
M	M	M	Y	7.90
M	C	Y	M	6.99
M	M	Y	M	4.74
M	C	M	M	4.72

[a]Critical difference for 1% significance by Scheffe's procedure is 1.43 × 10^7 cal/ha.

[b]Y,M,C = yam, maize, and cassava, respectively, occupying the plots.

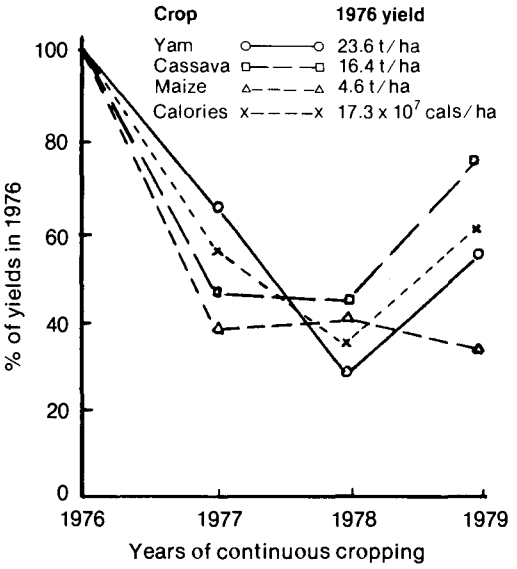

Fig. 1. *Decline in yield of yam, maize, and cassava with 4 years of continuous cropping. Yields are averaged over all phases carrying the respective crops.*

cal/100 g dry weight for yam, maize, and cassava, respectively (Oyenuga 1968).

RESULTS

The 1978 and 1979 harvest data are the only yields for which it is possible to make inferences.

1978 YIELDS

The yam yields from the five treatment phases or sequences differed significantly from one another at the 5% level of probability. Best yields were obtained from the sequences cassava–cassava–yam (7.59 t/ha) and cassava–yam–yam (6.88 t/ha); the sequences yielding least were maize–maize–yam (4.85 t/ha) and yam–yam–yam (4.76 t/ha). Maize–cassava–yam was intermediate (6.22 t/ha). Nematode populations at harvest ranged from 160/g of soil to 255/g; the differences were not significant. The lowest percentage of tubers damaged was with the maize–maize–yam sequence (10.9); the highest with the maize–cassava–yam (19.5), but none of the differences were significant.

Cassava yields after the third year of cropping were significantly different at the 1% level. The yield of the last crop from the yam–maize–cassava sequence was 4.93 t/ha and was significantly lower than were yields from cassava–cassava–cassava and maize–cassava–cassava sequences (7.05 and 7.62 t/ha respectively).

Treatment differences in 1978 maize grain yields were highly significant. Soils cropped with cassava–yam–maize yielded 2.70 t of grain, which was significantly higher than were yields from maize–cassava–maize (1.82 t/ha), yam–yam–maize (1.80 t/ha), and maize–yam–maize (1.61 t/ha). Lowest yields were recorded for cassava–maize–maize (0.58 t/ha) and maize–maize–maize (0.45 t/ha).

1979 YIELDS

Tuber yields from plots where yam followed 3 years of maize (13.86 t/ha) or cassava (13.29 t/ha) were superior to yields where yam followed other sequences. However, yield differences in 1979 were not significant. Lowest yields were recorded in plots where yam followed the basic rotation of yam–maize–cassava (10.16 t/ha). As in 1978, differences in nematode populations and incidence of cracks could not be attributed to the sequences. In 1979, differences in cassava yields attributable to sequence were not significant. Highest yields were from plots of cassava following maize–yam–maize (13.55 t/ha) and, as in the case of yams, lowest yields were given by cassava following the basic rotation (8.44 t/ha).

Very few significant differences in maize yields were obtained again in 1979. Yields where maize followed the sequence yam–maize–cassava were the lowest, as in the case of yam and cassava, and differed significantly from the rest.

Total yield of calories from cropping sequences where the root crops, yam and cassava, occupied the land for a major portion of the period were much higher than were those where maize dominated the sequence (Table 1).

Annual relative mean yields of the respective crops showed a steady decline (Fig. 1) for the years 1977 and 1978; this decline was more pronounced in the case of yam. Thereafter, the yields of yam and cassava rose, relative to 1978 yields, whereas the yield of maize was just under the 1978 level.

DISCUSSION

Our investigation provided answers to the two questions for which the study was designed. Results have shown that the basic rotation of yam fb maize fb cassava is significantly inferior to the other sequences, as far as the three crops are concerned. Best yields for yam and cassava were obtained when these crops followed 3 years of maize; their worst yields were recorded when they

followed 2 or 3 consecutive years of themselves. For soils in Umudike, Obi (1965) reported earlier that each of the three crops gave its best yield when it succeeded bush fallow cut down and burned in the year of test cropping, and its worst yield when it succeeded itself.

Judged by the total caloric yield for the 4 years of cropping, the 21 sequences were not of equal productivity. Highest energy was harvested in sequences dominated by the root crops. This is not surprising as root crops by virtue of their high harvest indices and caloric content are better energy harvesters.

The observed yield decline with continuous cropping, even with the heavy manuring and fertilizer additions, highlights a second finding of the study — that yield cannot be sustained and fertility maintained under the heavy rainfall typical of the area through the use of organic manures and fertilizers. Similar reductions following successive croppings had been reported for Umudike (Obi 1965), Malaysia, Trinidad, Guyana, Honduras, Guatemala, and the forest zone of Ghana (Nye and Greenland 1960). At Umudike, yields of a second crop of yam, maize, and cassava declined to 67.5, 82.7, and 59.8%, respectively, of their first yields (Obi 1965). A similar result was recently obtained for continuous cultivation of cassava in Umudike; yield declines in the second, third, and fifth years of continuous cassava were, respectively, 33.8, 45.8, and 49.1% of those in the first (Odurukwe 1980). In the forest zone of Ghana, soils maintained under a continuous rotation of maize and cassava for 8 years showed a steady decline in yield, even with supplemental addition of compost and fertilizers.

Other reports have shown that under certain conditions yields can be sustained in continuous cropping, with or without fertilizer application. For example, yields were fully maintained for 8–11 years in Kano under continuous guinea corn, millet, and groundnut (Obi 1965) and for 9 years with a loss of less than 25% under a continuous rotation of maize and cassava in the savanna zone of Ghana (Nye and Greenland 1960). Results of long-term studies at seven sites in northern Nigeria did not suggest any general decline in maximum crop yields over 5–6 years under intensive cropping, yields being maintained by judicious fertilizer use (Heathcote 1975).

The apparent inconsistencies in the responses are attributable to differences in rainfall and soils in the various ecological zones. Umudike with its high rainfall and sandy soils, typical of most of the rain forest zone of southeastern Nigeria is expected to have a higher rate of organic matter decomposition, heavier leaching losses, higher soil erosion, and more rapid decline of general fertility with continuous cropping.

Considering the heavy supplements of manure and fertilizers in this investigation we believe yield declines reflected a depletion of the trace and minor elements contained in the soil, proliferation of pests and diseases, and the deterioration of the soil's condition. Changes in the soil's nutrient status in the course of this investigation will be the subject of another paper.

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INTERCROPPING OF PLANTAINS, COCOYAMS, AND CASSAVA

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At the University of Ghana, Agricultural Research Station, Kade, the yields of marketable products obtained from pure stands of plantains, cocoyams, and cassava were compared with those from mixed stands. There were four mixed groups: plantains–cocoyams–cassava; plaintains–cocoyams; plantains–cassava; and cassava–cocoyams. The plaintain–cocoyam intercrop showed a slight increase in yield (5%) for the plantains, but in all other mixes the intercrop yielded less than did the pure stands. The decline in yields when plantains were one of two intercrops (with either cocoyams or cassava) was not significant. However, when plantains, cocoyams, and cassava and when cocoyams and cassava were intercropped together, the decline in yields compared with pure stands was very highly significant. The results of this work provide useful agronomic considerations for the design of plantains, cocoyams, and cassava cropping patterns.

La Station de recherche agricole de l'Université du Ghana à Kade a comparé les rendements des produits commercialisables de plantains, de taros et de manioc cultivés en monoculture avec ceux de culture associée. Cette dernière a porté sur quatre récoltes: plantains + taros + manioc; plantains + taros; plantains + manioc; et manioc + taros. L'association plantains + taros a donné un rendement inférieur de 5%, et dans toutes les autres associations, les rendements ont été inférieurs à ceux de la monoculture. La baisse de production de taros ou de manioc lorsque cultivés en association avec le plantain était relativement peu importante. Cependant, elle s'écartait des rendements de la monoculture lorsque l'association comprenait plantains + taros + manioc et taros + manioc. Les résultats de cette recherche apportent d'utiles considérations agronomiques à la détermination de modèles de rotation pour les plantains, les taros et le manioc.

In the humid tropics, which cover most of West Africa, plantains, cocoyams, and cassava form the main starchy staples. These crops may be grown either in pure stands or in mixed or intercropping systems. In an intercropping system, the crops are grown in a sequence, with some variation from one ecological zone to another. In the forest zone of Ghana, for example, the cropping sequence has been described elsewhere by Doku (1967) and Karikari (1971a,b). Intercropping is very widespread and is practiced in other areas of the humid tropics (Jurion and Henry 1967; Ruddle 1974; Wilson 1976), but there is very little published information comparing the productivity of pure stands with that of mixed cropping of plantains, cocoyams, and cassava.

Devos and Wilson (1978) compared the productivity and efficiency of plantain–cocoyam intercropping in Nigeria and found a high land-equivalent ratio (LER) — the land area in pure stands giving yields equivalent to 1 ha of land in mixed stands — for the combination, indicating its suitability for regions where pressures on land are high. This is the only published information available on this subject in recent years. My work, therefore, was undertaken to produce more information on productivity of different cropping systems in which plantains, cocoyams, and cassava were used in various combinations.

MATERIALS AND METHODS

The planting materials used for this experiment were the sword-type of suckers of plantains, variety Apantu, corms of cocoyams, variety Mankani pa (as described by Karikari 1971a), and stakes of cassava, variety Ankara. All the materials were selected from healthy mother plants. The plantain suckers were pared of all adhering tissues, washed, and dipped into a solution of 2000 ppm Nemagon. The cocoyam corms were cut into sets weighing 100–120 g each, dipped into a solution of 1000 ppm Benomyl, and dried in the sun for 24 hours. The cassava stakes were cut to 20 cm long.

The experimental plot covered an area of approximately 4 ha. The area had been cultivated with two crops of maize and winged beans in the

Fig. 1. *Plantain–cocoyam–cassava intercrop.*

previous 2 years. It was divided into seven equal plots, each plot measuring approximately 0.5 ha with 3 m between each plot as border rows.

The following treatment combinations were assigned at random to the plots: pure stands of plantains, cocoyams, and cassava and mixed stands of plantains–cocoyams–cassava; plantains–cocoyams; plantains–cassava; and cassava–cocoyams. Before the planting, all plots received nitrogen, 50 kg/ha (urea, 46% N); phosphorus, 50 kg/ha (triple superphosphate, 22% P), and potassium, 10 kg/ha (muriate of potash, 45% K).

The plantains were planted 3 × 3 m apart, the pure stands having 225 plants; the cocoyams and cassava were planted 1.5 × 1.5 m apart — about 800 plants per plot in the pure stands. The same spacings and number of plants were arranged in the mixed cropping plots. Planting was done from 9 to 13 May 1977.

Harvesting of the cocoyams was done between 20 and 24 February 1978, i.e., 40 weeks after the planting; the cassava was harvested between 8 and 12 May 1978, i.e., 52 weeks after being planted; and the plantains were harvested as they matured, the first harvesting being done on 12 April 1978. The harvesting of the plantains continued for 6 months, the last harvest being taken on 12 October 1978 by which time 80% of the crop had been harvested. The weights of all marketable products from the harvests were recorded.

RESULTS

The yields of marketable plantains, cocoyams, and cassava from pure stands were, respectively, 22.4 t/ha, 8.0 t/ha, and 33.6 t/ha. In the plantain–cocoyam–cassava intercrop (Fig. 1), however, the yields were 16.4 t/ha, 4.7 t/ha, and 15.0 t/ha, corresponding to a decline in yields of 26.8%, 41.3%, and 35.4%, respectively. In the plantain–cocoyam intercrop (Fig. 2), the marketable products were 23.5 t/ha and 7.8 t/ha, a 5.0% increase in the yield of plantains and a 2.5% decline in the yield of cocoyams. With the plantain–cassava intercrop (Fig. 3), the yields were 20.4 t/ha and 32.0 t/ha, corresponding to 10.7% and 4.8% declines, respectively. There was a much higher decline in yields from the two root crops, cocoyams and cassava, when planted together, the yields being 4.6 t/ha and 20.8 t/ha and corresponding to declines of 42.5% and 38.1%, respectively.

The land-equivalent ratios (LERs) were 1.8, 2.1, 2.0, and 1.2 for the plantain–cocoyam–cassava; plantain–cocoyam; plantain–cassava; and cocoyam–cassava intercrops respectively.

DISCUSSION

Mixed cropping is the simultaneous growth of two or more useful plants on the same plot. The practice

Fig. 2. *Plantain–cocoyam intercrop.*

has been considered primitive, less productive, and less efficient than sole cropping. This misconception may be due to the fact that the system is very limited in terms of mechanized agriculture, to which sole cropping can be more easily subjected. Mixed cropping is, however, widespread in tropical Africa and is especially complex in the rain forest where plantains and root crops form the main staples.

In traditional Ghanaian practice, the crops in mixed cropping are rarely grown in rows and usually one crop takes prominence over the others. It is always the predominant crop that is planted first and more often allowed to establish before other crops are planted in a system of relay. The population of the relay crops is only a proportion of the predominant crop.

For experimental purposes and uniformity, however, I had all the crops planted at almost the same time without considering any one crop as predominant. Also, the populations used in the pure stands were maintained in all plots. In this experiment, the yields of the plantains, cocoyams, and cassava in the sole cropping compared favourably with yields reported in the literature (Doku 1966; Karikari 1971a, b, 1974; Devos and Wilson 1978).

The high reduction in the yields when the three crops were planted together was expected because of competition. Although the plantains were spaced widely, the planting of two other crops probably brought about a high interspecific competition mostly in the form of shade, resulting in low yields. Both cocoyams and cassava are root crops, which are very demanding in their nutrient requirements, and may compete for nutrients as well.

The LER of 1.8 obtained under this system was high, but slightly misleading, because the contributions made by individual crops was low — 0.7, 0.6, and 0.4, respectively, for the plantains, cocoyams, and cassava.

The increase in the yield of plantains by 5% when they were intercropped with cocoyams is interesting. Although the cocoyams' yield was lower (decline of 2.5%) in the mix, their presence with the plantain leaves caused early closure of the canopy, thus suppressing weeds, maintaining soil moisture, and increasing the efficiency of the system. It was,

Fig. 3. *Plantain–cassava intercrop.*

therefore, not surprising that the LER in this cropping was 2.1 and the highest among the systems.

The plantain–cassava intercrop showed a yield decline of about twice as much as the plantain–cocoyam intercrop with an LER of 2.0. This decline may be due to the poor contribution of cassava in forming the canopy.

The cocoyam–cassava intercrop produced the lowest yield and was the system in which the highest decline of both crops was observed. Correspondingly, the LER of 1.2 obtained for the cassava–cocoyam intercrop system indicated the lowest utilization potential. This might have been caused by the fact that both are root crops and may demand similar soil nutrients. Also, the canopy formed was not close enough to check weed growth.

CONCLUSIONS

Plantain–cocoyam–cassava intercropping appears to be well-suited to the humid tropics, including the forest zones of Ghana. In one way or another, each crop appears to benefit from the presence of the other. There is a general yield reduction of different magnitudes when two or more of the crops are planted as intercrops rather than in pure stands, but the efficiency of the combination corresponds with the LER. Some agronomic observations of the cropping pattern were that:

- Yields were significantly lower when the three crops were planted together;
- When plantains were used as one of the intercrops with one root crop (i.e., cocoyam or cassava), the system became more efficient;
- The two root-crop system reduced yield very significantly and was least efficient; and
- Regardless of economic factors, the suitability of the systems was in descending order, plantains–cocoyams; plantains–cassava; plantains–cocoyams–cassava; and cocoyams–cassava corresponding to LERs of 2.1, 2.0, 1.8, and 1.2, respectively.

WEED CONTROL IN MAIZE–CASSAVA INTERCROP

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Two improved cassava cultivars consisting of a profusely branching type (TMS 30395) and an upright, moderately branching type (TMS 30001) were grown at two population densities as components of mixtures involving two maize (TZB) populations. Maize yield was depressed by TMS 30395 at the higher cassava population density of 10 000 plants/ha but not at 5000 plants/ha. Cassava cultivar TMS 30001 did not affect maize yield at either of the two population densities. Two hand weedings or the use of a preemergence herbicide (Primextra) limited yield reductions caused by weeds in the maize–cassava intercrop. Root yield was generally higher for TMS 30001 than for TMS 30395. The highest root yield for each cultivar was obtained when 10 000 cassava plants/ha were intercropped with maize at 20 000 plants/ha. This combination gives the optimum plant population (30 000 plants/ha) for the mixture. The highest total food energy and the lowest weed weight were observed at this population. Cost of weeding was lowest where the herbicide, Primextra, was used. This treatment gave the highest return on investment at the optimum crop combination.

Deux cultivars améliorés de manioc, le TMS 30395 à feuillage abondant et le TMS 30001 à feuillage modéré érigé ont été cultivés à densité différente en association avec deux peuplements de maïs (cv. TZB). TMS 30395 a réduit les rendements de maïs lorsque la population comprenait 10 000 individus par hectare mais n'eut aucun effet sur celle de 5 000 plantes par hectare. Le cultivar TMS 30001 n'a pas affecté la production de maïs quelle qu'ait été la densité de la population associée. Deux sarclages ont été nécessaires ou l'emploi d'un herbicide en pré-levée (Primextra) afin de réduire au minimum l'action des mauvaises herbes. Le rendement en tubercules a été généralement plus élevé avec TMS 30001 qu'avec TMS 30395. Et la production de tubercules pour chaque cultivar a été plus élevée lorsque la culture associée comprenait un peuplement de manioc de 10 000 plants par hectare et celle du maïs de 20 000 plants par hectare. Cette combinaison de 30 000 plants par hectare est la meilleure proportion pour une production optimale. C'est également dans cette proportion qu'on a obtenu l'énergie alimentaire totale la plus élevée et le plus faible volume de mauvaises herbes. Le sarclage a été le moins coûteux avec l'emploi de l'herbicide Primextra. Ce traitement a été le plus rentable pour cette combinaison de cultures associées comprenant le maïs et le manioc.

Mixed cropping constitutes a major component of the traditional cropping system in tropical Africa (Okigbo and Greenland 1976). In most parts of the world, cassava is grown as an intercrop by smallholder farmers. Crops commonly intercropped with cassava include food legumes, cereals, and horticultural crops. Maize–cassava appears to be the most popular intercrop among farmers in tropical Africa, Latin America, and Asia (Okigbo 1978; Mureno and Hart 1979; and Kumar and Hrishi 1979).

Farmers intercrop for a variety of reasons including insurance against crop failure, better and more efficient use of labour, prevention of erosion, and protection against crop pests (Watters 1971; Andrew 1975; Norman 1975). Although a desire to control weeds may have influenced the evolution of cropping patterns, the farmer generally uses very wide spacings adjusted more to the fertility level of the soil than to early canopy cover and weed control. Lagemann (1978), in a study of the traditional farming systems of three villages in eastern Nigeria, noted that the average plant population density of a mixture of arable crops in the fields was only 12 000 plants/ha. This figure is low compared with the 30 000 plants/ha generally recommended for arable crop mixtures.

Low plant densities mean that large areas of soil surface are exposed and so favour weed establishment. Effective use of intercropping to suppress weeds requires adequate plant populations and spatial arrangements of crops in the mixture. The objective of this study was to assess the impact of plant type and population density on the effectiveness of selected weed control treatments.

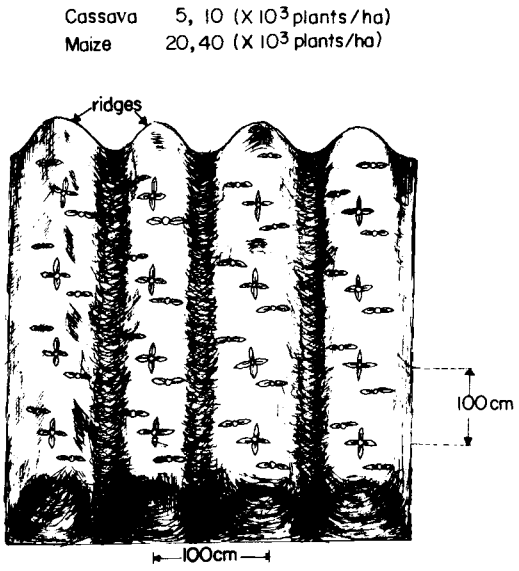

Fig. 1. *Effect of maize plant population on maize grain yield.*

MATERIALS AND METHODS

The experiment was set up in an alfisol (Apomu sandy loam soil) at the International Institute of Tropical Agriculture. Two improved cassava cultivars consisting of a profusely branching type (TMS 30395) and an upright, moderately branching type (TMS 30001) were used at two spacings (100 × 100 cm and 100 × 200 cm) as components of mixtures involving maize (cultivar TZB). The maize was intercropped at a spacing of 100 × 25 cm (Fig. 1). The two crops were planted at the same time. Cassava stakes were 25 cm long and were planted on the top of ridges in a slanting position (approximately 45°). Maize was planted on both sides of the ridges at two seeds per hill and thinned to one stand/hill 2 weeks after emergence. In addition to the intercrop treatments, weed-free control plots of sole maize and sole cassava, each at the various plant populations used in the intercrop, were included. Fertilizer was applied (N, P_2O_5, and K_2O, 30 kg/ha) during land preparation, and 60 kg N/ha was applied to the 4-week-old maize as side dressing.

Weed-control treatments were one hoe weeding; two hoe weedings; preemergence application of a formulated mixture of atrazine and metolachlor (2.5 kg a.i./ha); a weed-free plot; and an unweeded control plot. Data on crop performance, weed control, and yield of economic components of the crops were collected and statistically analyzed.

RESULTS AND DISCUSSION

The results showed that maize yield (at 40 000 plants/ha) was depressed in the profusely branching cassava cultivar (TMS 30395) at 100 × 100 cm spacing but not when the cassava spacing was 100 × 200 cm (Table 1). Reduction in maize yield

Table 1. Effect of cassava (TMS 30395 and TMS 30001) spacing (population) on yield of maize (TZB).[a]

		Maize grain yield (t/ha)			
		TMS 30395 spacing		TMS 30001 spacing	
	Weed control	1.0 × 1.0 m	2.0 × 1.0 m	1.0 × 1.0 m	2.0 × 1.0 m
40 000 maize plants/ha	Weeded at 2 WAP	1.84	1.83	1.85	2.59
	Weeded at 2+5 WAP	2.28	3.10	2.54	2.30
	Primextra 2.5 PE	2.69	2.35	3.25	2.50
	Weed free until harvest	2.81	3.25	3.13	3.11
	Weedy	0.66	1.09	1.35	0.96
Mean		2.06	2.03	2.43	2.29
LSD 0.05 (within cassava)[b]		1.46		0.92	
20 000 maize plants/ha	Weeded at 2 WAP	1.85	1.30	1.90	1.65
	Weeded at 2+5 WAP	1.12	1.26	2.09	2.07
	Primextra 2.5 PE	1.32	1.46	2.14	1.26
	Weedy	0.37	0.42	1.47	1.08
Mean		1.17	1.11	1.90	1.52
LSD 0.05 (within cassava)[b]		0.74		0.86	

[a]Yield from sole maize plots, kept weed free, was 3.24 t/ha at 40 000 plants/ha and 2.33 at 20 000 plants/ha.

[b]LSD 0.05 for comparison of means of different cassava spacings at 40 000 plants/ha maize is 1.61 t for TMS 30395 and 1.46 t for TMS 30001; at 20 000 plants/ha maize, it is 0.68 t for TMS 30395 and 1.10 t for TMS 30001.

Table 2. Effect of maize spacing and population on yield of cassava (TMS 30395 and TMS 30001).[a]

		TMS 30395 (TMS 30001) fresh weight yields (t/ha)	
		Maize spacing	
	Weed control	1.0 × 0.25 m	1.0 m × 0.5 m
10 000 cassava plants/ha	Weeded at 2 WAP	10.80 (13.56)	15.29 (16.78)
	Weeded at 2+5 WAP	13.07 (18.29)	15.55 (25.08)
	Primextra 2.5 (preemergent)	13.63 (16.23)	23.28 (34.78)
	Weed free until harvest	13.07 (21.18)	23.57 (30.94)
	Weedy	6.27 (7.71)	6.83 (9.32)
Mean		11.37 (15.39)	16.9 (23.38)
LSD 0.05 (within maize)[b]		14.3 (9.31)	
5 000 cassava plants/ha	Weeded at 2 WAP	10.31 (7.59)	16.50 (14.12)
	Weeded at 2+5 WAP	11.05 (15.99)	15.94 (13.56)
	Primextra 2.5 (preemergent)	11.69 (13.61)	19.40 (20.56)
	Weed free until harvest	10.68 (14.31)	19.24 (21.92)
	Weedy	4.49 (4.42)	4.02 (3.09)
Mean		9.65 (11.18)	15.02 (14.65)
LSD 0.05 (within maize)[b]		8.71 (8.21)	

[a]Yield from sole cassava plots, kept weed free, was 41.79 t/ha at 10 000 plants/ha and 29.73 t/ha at 5000 plants/ha.
[b]LSD for comparison of means of different maize spacings at 10 000 plants/ha cassava is 13.2 t for TMS 30395 and 11.4 t for TMS 30001; at 5000 plants/ha, it is 11.1 t for TMS 30395 and 20.12 t for TMS 30001.

caused by uncontrolled weed growth was greater at the narrower cassava spacing than at the wider spacing (77% and 67% respectively). This may have been caused by increased interspecific and intraspecific competition among weeds and crop mixtures. The yield reductions were greater than values generally observed in sole-cropped maize under identical growing conditions. The cassava cultivar TMS 30001 did not depress maize yield at any of the spacings used in this study (Table 1).

Cultural weed control involving two weedings by hand or the use of a preemergence herbicide was necessary to minimize yield reduction caused by weeds in the maize–cassava intercrop. The herbicide caused no visible phytotoxicity to either maize or cassava. Intercropped maize at a plant population of 20 000 plants/ha generally produced lower yields than did the same population on a pure stand.

Root yield of TMS 30395 at the two cassava spacings used in this study was depressed by maize at a population of 40 000 plants/ha but not at 20 000 plants/ha (Table 2). When good weed control was provided, root yield of TMS 30395 intercropped with maize at 20 000 plants/ha was identical to yield of the sole-cropped cassava irrespective of the cassava population. Root yield in the herbicide-treated plots was as high as that in the weed-free plots. Uncontrolled weed growth caused more yield reduction in cassava at high plant populations than at the low levels due to greater weed–crop interference at high plant densities.

Root yield was depressed at all intercrop combinations involving TMS 30001 (Table 2) but more so at a maize population of 40 000 plants/ha than at 20 000 plants/ha. However, crop sensitivity to weed interference was greater at the lower population. Although, generally, cassava yield was lower in plots weeded only once than in plots with other

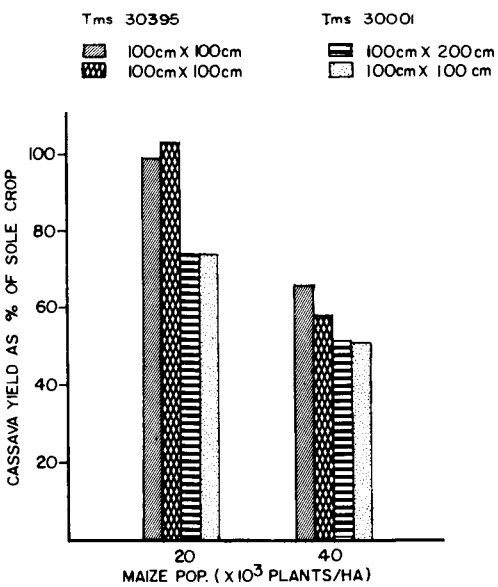

Fig. 2. *Effect of maize plant population on cassava root yield.*

Table 3. Effect of plant population on land equivalent ratio in maize–cassava intercrop.

Crop spacing		Population (plants/ha)	Land equivalent ratio		
Cassava	Maize		TMS 30395	TMS 30001	Mean[a]
2 × 1 m	1 × 0.5 m	25 000	1.86	1.30	1.58
1 × 1 m	1 × 0.5 m	30 000	1.68	1.90	1.79
2 × 1 m	1 × 0.25 m	45 000	1.59	1.47	1.53

[a]LSD (0.05) for comparison of means within one cultivar is 0.34: between the two cultivars is 0.71: the coefficient of variation is 12%.

weed-control treatments, this difference was very pronounced at the lower plant population.

How the various maize populations affect cassava root yield under weed-free conditions is shown in Fig. 2. The cassava cultivar TMS 30001 was more affected by the maize intercrop than was TMS 30395. Up to 50% yield reduction occurred in TMS 30001 when it was intercropped with maize at 40 000 plants/ha.

Lodging in the maize–cassava intercrop was affected by plant population as well as cassava cultivar (Fig. 3). When the two cassava cultivars were grown separately, lodging was kept at about 10% of the total stands. The greatest amount of lodging was observed in the maize–cassava intercrop where the maize population of 40 000 plants/ha was maintained. The upright cassava cultivar (TMS 30001) was more susceptible to lodging than the low, profusely branching TMS 30395. At 100 × 100 cm spacings, TMS 30395 practically suffered no lodging.

All the maize–cassava intercrop populations had land-equivalent ratios (LERs) greater than one, an indication that this intercrop has an overall yield advantage over growing each crop alone on the available land. The highest mean LER for the intercrop was obtained at a total maize–cassava population of 30 000 plants/ha, and the highest

Table 4. Effect of plant population and weed control on food energy values (calories) and weed growth in maize/cassava intercrop.

		Energy values (× 10^6 cal) cassava cultivars		Dry weight of weeds (t/ha) in	
	Weed Control	TMS 30395	(TMS 30001)	TMS 30395	(TMS 30001)
25 000 plants/ha	Weeded at 2 WAP	29.23	(27.08)	3.61	(3.05)
	Weeded at 2+5 WAP	28.24	(27.60)	1.20	(0.71)
	Primextra 2.5 PE	32.58	(35.12)	1.61	(2.11)
	Weed free	34.53	(37.33)		
	Weedy	7.47	(6.24)	4.97	(4.97)
30 000 plants/ha	Weeded at 2 WAP	29.38	(31.79)	2.74	(2.53)
	Weeded at 2+5 WAP	27.17	(44.84)	1.13	(1.14)
	Primextra 2.5 PE	39.39	(59.08)	1.17	(1.49)
	Weed free	40.63	(51.72)		
	Weedy	11.49	(19.09)	4.63	(3.86)
45 000 plants/ha	Weeded at 2 WAP	21.89	(20.58)	2.31	(2.64)
	Weeded at 2+5 WAP	23.50	(32.03)	0.47	(1.27)
	Primextra 2.5 PE	27.73	(29.21)	1.54	(0.87)
	Weed free	27.52	(32.44)		
	Weedy	10.57	(10.00)	4.62	(4.65)
50 000 plants/ha	Weeded at 2 WAP	23.38	(26.81)	2.51	(2.19)
	Weeded at 2+5 WAP	27.64	(36.34)	1.83	(0.77)
	Primextra 2.5 PE	29.88	(35.81)	1.49	(1.53)
	Weed free	29.52	(42.71)		
	Weedy	11.69	(16.30)	4.96	(4.65)
LSD (0.05) for comparison of means within each population		16.84	(13.00)	1.56	(1.34)
LSD (0.05) for comparison of means of different populations		16.52	(15.85)	1.46	(1.27)

Table 5. Effect of weed control methods on economic return in maize–cassava intercrop.

Population (plant/ha)	Weed control	Cost of weeding (Naira)[a]	Gross return (Naira) TMS 30395	Gross return (Naira) TMS 30001	Net return (Naira)[b] TMS 30395	Net return (Naira)[b] TMS 30001
30 000	Hoe weeding at 2+5 WAP	138.00	1271.83	2121.53	1133.83	1983.53
	Primextra 2.5 PE	42.50[c]	1813.88	2737.19	1771.38	2694.69
50 000	Hoe weeding at 2+5 WAP	138.00	1406.53	1802.43	1268.53	1664.43
	Primextra	42.50	1539.53	1848.71	1497.03	1806.21

[a]Two weedings in maize/cassava require 278 h/ha; cost is based on 6 h/day @ 3.00 Naira/day; 1.00 = U.S. $1.80.
[b]Net return does not include other production costs and these are identical for both weeding methods.
[c]Cost of herbicide plus labour; a day for each sprayer operator and assistant @ 3.00 Naira/day.

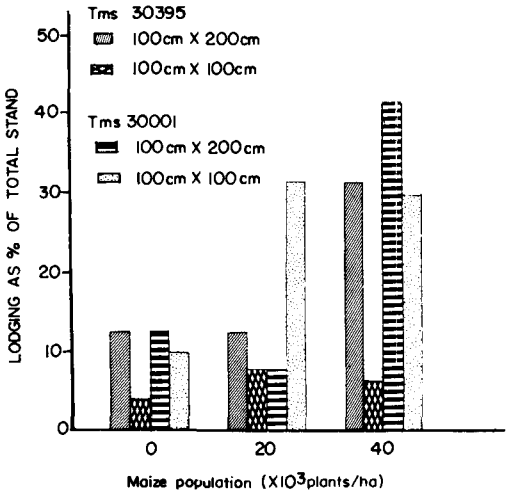

Fig. 3. *Effect of maize plant population on maize cob yield.*

LER for TMS 30001 was also obtained at this total plant population (Table 3). The concept of LER has been used by several authors to assess the advantages of sole and intercropping systems (Francis et al. 1976; Trenbath 1976).

At each plant population, the highest food energy values (kilocalories) were obtained in plots that were kept weed-free throughout the growing season either by repeated weeding by hand or by application of herbicide (Table 4). The highest energy values were obtained when each cassava cultivar was intercropped at 10 000 plants/ha with maize at 20 000 plants/ha. Also, the mean weed weight was lowest at this population mix (Table 4).

The best weed-control treatments in this study were two timely weedings by hand or the use of the herbicide Primextra. The lowest unit cost for weed control was obtained when the herbicide was used (Table 5). This treatment accounted for the highest return on investment, especially at the optimum crop combination (30 000 plants/ha).

It is generally assumed that herbicides are too expensive for the average farmer to use. Results reported in this paper show that at least in Nigeria labour for weeding is in fact manyfold more expensive than is herbicide. Besides, labour for routine farm operations has become very scarce as a result of accelerated migration of rural dwellers to urban centres. Even in countries where the daily wage is low, labour has in recent times become unreliable and often unavailable at the critical time of weed interference. Herbicide use not only provides the needed weed control at the time it is most needed by the crop but also reduces the farmer's input costs in weed control. To make chemical weed control attractive, there is need to improve on herbicide availability to small farmers in consumer-usable small packages. This type of packaging will require the cooperation of chemical industries and governments in the developing countries.

I wish to acknowledge the help given by G. Heys in providing the improved cassava stakes used in this study and the technical assistance provided by R.A. Raji in the course of the field experiments.

EFFECT OF MAIZE PLANT POPULATION AND NITROGEN APPLICATION ON MAIZE – CASSAVA INTERCROP

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We studied the effects that maize populations had on the performance of maize and cassava intercropped on an Egbeda soil (oxic paleustalf) at Ibadan. Maize and cassava were spaced 100 × 100 cm, cassava planted between maize along the same row. Maize plants/hill were varied from 1 to 7 giving a population 10–70 × 10^3 plants/ha. Increasing maize populations from 10 to 30 × 10^3 plants/ha significantly increased maize grain yield and had no significant effect on cassava root yield. Higher populations, however, had no effect on grain yield but significantly depressed root yield. It seems that three maize plants/hill is optimum. The effects of nitrogen rates on intercropped maize and cassava were studied on Alagba soil (oxic paleustalf) at Ikenne. The soil had been *Eupatorium* fallow before the study. In the first year, no response to N was observed on sole or intercropped maize, but, with early harvest, root yield of TMS 30395 showed significant depression with N application and intercropping. During the second year, both the sole and the intercropped maize showed a significant response to N but not the cassava crop. Maize–cassava intercropping appears to be more efficient than the corresponding sole crops as indicated by the higher land equivalent ratios (LERs).

Étude des effets des peuplements de maïs sur les rendements de la culture associée maïs + manioc sur des sols Egbeda (Oxic paleustalf) à Ibadan. Les deux espèces ont été plantées sur une même rangée, en alternance, avec des écartements de 100 × 100 cm. Chaque billon comprenait de 1 à 7 plants de maïs soit un peuplement de 10 × 70 × 10^3 plants/ha. L'augmentation des semis de maïs de 10 à 30 × 10^3 plants a sensiblement accru le rendement en grains sans affecter la production de tubercules du manioc. Des peuplements plus denses ont donné le même résultat en termes de grains mais par contre, le rendement en tubercules a accusé une importante baisse. La densité optimale de plants par billon est de 3. A Ikenne, on a étudié les effets de l'apport d'azote au maïs et au manioc cultivés dans des sols Alagba (Oxic paleustalf). Après une année d'essais sur une jachère où poussait l'Eupatorium, on n'a pu observer de réactions à l'apport de N tant chez le maïs en monoculture que chez le maïs et le manioc en association; mais une récolte précoce de tubercules a démontré une baisse de rendement considérable due à la culture associée et à l'apport de N. Au cours de la deuxième année, le maïs cultivé selon les deux façons a bien réagi à N contrairement au manioc. L'association manioc + maïs semble être plus efficace que le maïs en culture pure, tel que l'indique le quotient supérieur de l'équivalence des terres.

In traditional farming systems in the humid tropics, cassava is known to be intercropped with a number of annual food and tree crops (Weber et al. 1978). According to Okigbo and Greenland (1976), about half the cassava grown in tropical Africa is intercropped. The most popular forms of cassava intercropping are mixed intercropping in which the associated crops have no distinct row or spatial arrangements and relay intercropping in which the associated crops are grown simultaneously only during part of the life cycle of each crop. Though in humid tropical Africa cassava is known to be mixed with a wide variety of crops, some principal staple food and subsidiary crops can be identified (Okigbo 1978). Ezeilo et al. (1975) reported that cassava–maize, cassava–yam, and cassava–yam–maize are dominant mixed cropping systems on acid Ultisols in the forest zone of southeastern Nigeria. Agboola (1979) also reported that yam–maize–melon, yam–maize–cassava, and maize–cassava are widespread mixed cropping systems in the derived savanna and forest zone of southwestern Nigeria, which is dominated by high base status Alfisols and associated Entisols. Wilson and Agboola (1979) claimed that maize–cassava mixed cropping systems are the most popular and widespread in West Africa. They attributed this popularity to the high compatibility and complementarity of the crops, the fast-growing maize exploiting the environment early and the slow-growing cassava exploiting it later.

Despite the importance of the maize–cassava mixed cropping system, little information exists on the effects of intra- and interspecific competitions.

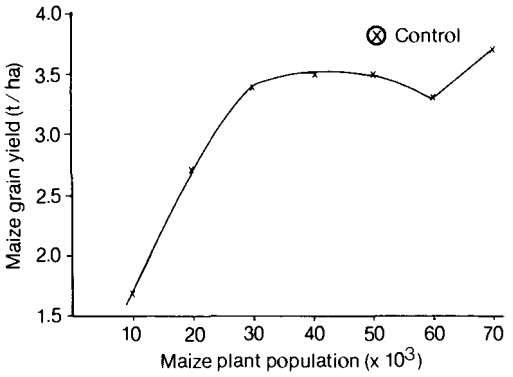

Fig. 1. *Planting arrangement for maize–cassava intercrop.*

Similarly, there is little information on the effects of soil fertility on the performance of the intercropped maize and cassava. Further studies, therefore, have been carried out on the subjects, and some of the results are reported in this paper.

Effect of Maize Density

In traditional maize–cassava mixed intercropping there is no set plant density, spacing, or spatial arrangements. However, wide intraspecific spacing appears to be common, high plant density being obtained by close interspecific spacing. Wilson and Adeniran (1974), in one study, observed intraspecific spacing for cassava ranging from 50 to more than 200 cm with a mean of 100 × 140 cm. Wilson (unpublished data) also observed that in West Africa farmers plant between 5 and 10 maize seeds/hill at spacings ranging from 50 to 120 × 120 to 200 cm. Some of the farmers thin to three plants/hill, but others allow all surviving plants to mature. The effects of varying maize densities on intercropped maize and cassava are not well understood, so a field trial was carried out at Ibadan in southern Nigeria.

The trial was located on sandy loam, Egbeda soil (oxic paleustalf). Maize variety TZPB was planted at a spacing of 100 × 100 cm with 1–7 plants/hill to give 10 000–70 000 plants/ha. Cassava was planted at the same time, spacing was also 100 × 100 cm, and the cassava was interspersed with maize along the same row (a population of 10 000 plants/ha). A control treatment of pure maize stand was added, at 75 × 25 cm spacing (53 200 plants/ha). A fertilizer rate of 40 N–20 P_2O_5–20 K_2O in kg/ha was applied to the maize crop. The trial was set up on a complete randomized block design with

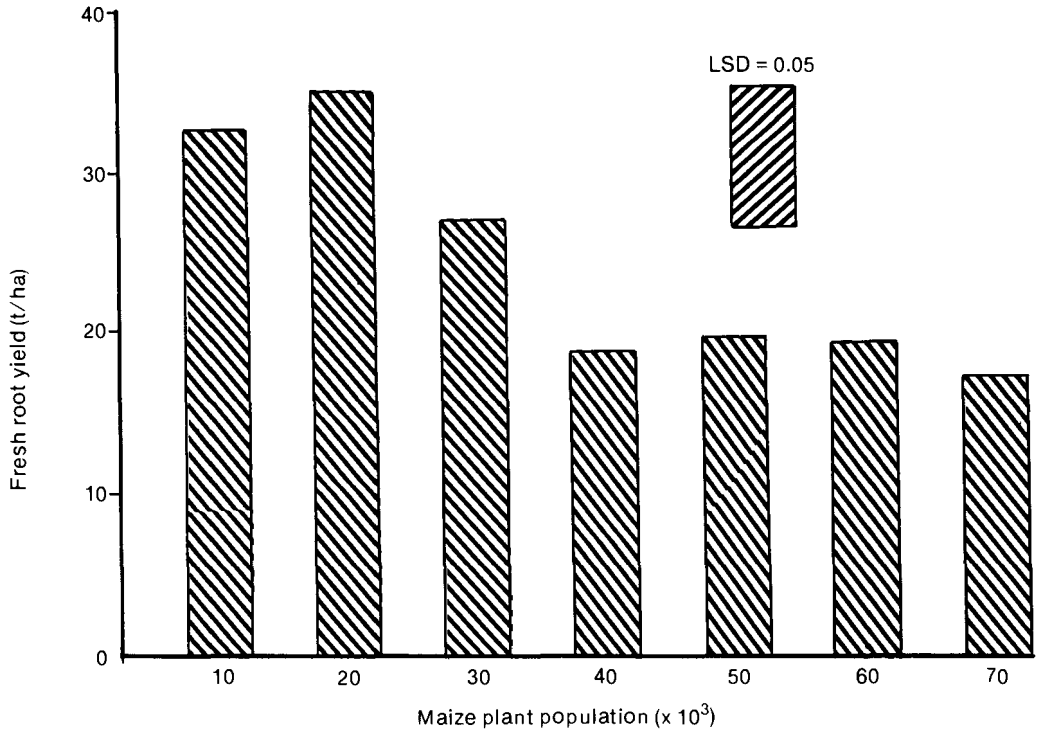

Fig. 2. *Effect of maize intercrop on cassava yield from weed-free plots.*

three replications. Cassava crop was harvested at 15 months after planting date.

Increasing the number of maize plants/hill from 1 to 3, which gave a corresponding population increase from 10 000 to 30 000 plants/ha, increased maize grain yield (Fig. 1) significantly (5% probability level). Further increases in plant population above 30 000 plants/ha resulted in small but not significant yield increases. Highest yields from intercropped maize were observed at 70 000 plants/ha, which is almost equal to the yield obtained in the control. For unexplainable reasons, there appears to be some yield depression at 50 000 plants/ha, which was also observed in a similar trial at Ikenne.

Increasing maize plant populations has a pronounced effect on cassava root yields, particularly at high plant populations (Fig. 2). Increasing the maize population to 30 000 plants/ha resulted in some but not significant yield decreases. Significant root yield (>35%) decreases were obtained at maize plant populations ≥ 40 000 plants/ha.

It thus appears that a maize population of 30 000 plants/ha combined with a cassava population of 10 000 plants/ha is optimum. Wilson and Adeniran (1974) from their study on the effects of spacing in traditional maize–cassava intercropping systems also observed that maize and cassava yield can be improved if the spacing is adjusted to these populations.

Recent studies (Wilson, unpublished) on the effects of maize varieties and plant densities on intercropped cassava also have shown that increasing maize populations from 30 000 to 60 000 plants/ha has no significant effect on maize grain yield but significantly depresses root yields from cassava. Cassava root yield was observed to be more depressed by the intermediate-maturing TZPB and local maize varieties than by the early-maturing TZE variety.

Though thinning the number of maize plants to three plants/hill may not be economic as far as maize grain yield is concerned, it may be economic in areas where green cob is sold. Cob size is negatively correlated with maize plant populations (Fig. 3); therefore thinning may have the advantage in increasing cob size. Sinthuprama (1978), for example, has shown that higher incomes can be obtained from maize–cassava intercropping where green cob rather than grain is harvested and sold.

NITROGEN RESPONSE

In traditional farming in humid tropical West Africa, maize and cassava are intercropped usually in the first year after land clearing and fallow-residue burning on the acid Ultisols. The intercrop is not normally continued because the nutrient deficiency and high soil acidity do not favour maize in subsequent years. In contrast, on highly basic Alfisol, where soil acidity is not a problem for the maize crop, the maize–cassava mixed cropping is often practiced for 2–3 years after bush fallow. Though decline in soil fertility with subsequent cropping is known to have an effect on crop yield, little information exists on the effects of changes in soil fertility on the performance of maize–cassava systems. A trial was, therefore, carried out at Ikenne, which is located about 60 km south of Ibadan, in the forest zone of southern Nigeria. The objective was to determine the nitrogen response by a maize–cassava intercropped system. The soil, an Alagba soil series, has a loamy sand texture derived from sandy sedimentary rocks, and, before this study, was newly cleared *Eupatorium* fallow. The soil had pH (in 1 : 1 soil : water ratio), 6.2; organic C, 1.22%; total N, 0.15%; CEC, 6.14 me/100 g; extractable Bray P-1, 4.3 ppm P.

In the trial, three nitrogen rates were compared (Table 1 and 2). Maize was planted at two spacings 1 × 1 m (three plants/hill) and 1 × 0.33 m (one plant/hill), giving 30 000 plants/ha, and cassava was planted at 1 × 1 m spacing, giving 10 000 plants/ha. Phosphorus was applied at a rate of 60 kg P_2O_5/ha and potassium at a rate of 90 kg K_2O/ha. During the first trial, cassava was harvested at 10 months, and in the second trial at 13 months after planting date.

On the newly cleared land, nitrogen application had no significant effect on the first or second season yields of maize in either the pure or intercropped stands (Table 1). Planting the maize at one or three plants/hill also had no effect on maize grain yield, and intercropping with cassava at a popula-

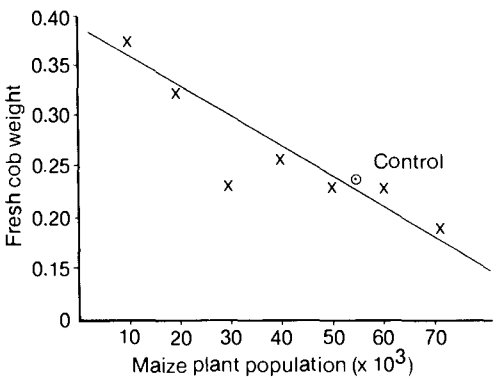

Fig. 3. *Effect of plant population on lodging in two cassava cultivars.*

Table 1. Effect of N application on yield of intercropped maize (variety TZPB) and cassava (variety TMS 30395) grown on Alagba soil (oxic paleustalf), 1979–80.[a]

N rate (kg N/ha)	Cropping mixture	Cassava fresh root yield (t/ha)	Maize grain yield (t/ha)	LER
0	Maize (1 × 0.33 m, 1 plant/hill)	–	1.80	–
	Maize (1 × 1 m, 3 plants/hill)	–	1.74	–
	Cassava (1 × 1 m)	30.12	–	–
	Maize (1 × 0.33 m) + cassava (1 × 1 m)	29.11	1.93	1.90
	Maize (1 × 1 m) + cassava (1 × 1 m)	28.89	1.87	2.00
60	Maize (1 × 0.33 m, 1 plant/hill)	–	2.30	–
	Maize (1 × 1 m, 3 plants/hill)	–	2.40	–
	Cassava (1 × 1 m)	30.90	–	–
	Maize (1 × 0.33 m) + cassava (1 × 1 m)	27.10	2.45	1.95
	Maize (1 × 1 m) + cassava (1 × 1 m)	29.50	2.39	1.95
120	Maize (1 × 0.33 m, 1 plant/hill)	–	2.28	–
	Maize (1 × 1 m, 3 plants/hill)	–	2.12	–
	Cassava (1 × 1 m)	28.65	–	–
	Maize (1 × 0.33 m) + cassava (1 × 1 m)	24.85	2.52	2.05
	Maize (1 × 1 m) + cassava (1 × 1 m)	29.68	2.10	2.03

[a]Maize crops slightly affected by drought; cassava harvested at 13 months.

tion of 10 000 plants/ha had no significant effect on maize grain yield. It should be noted, however, that the TZE variety did not perform well in this trial.

At the early harvest (10 months) the cassava root yields were significantly depressed both by nitrogen application and by intercropping with maize. There was a linear root-yield depression with increasing nitrogen rates from 0 to 120 kg N/ha. It appears that nitrogen application on this relatively fertile soil and also intercropping delay root bulking in cassava.

The second year, the maize crop was slightly

Table 2. Effect of N application on yield of intercropped maize and cassava (variety TMS 30395) grown on Alagba soil (oxic paleustalf), 1978–79.[a]

N rate (kg N/ha)	Croppig mixture	Cassava fresh root yield (t/ha)	Maize grain yield (t/ha)			LER
			First season (T2PB)	Second season (TZE)	Total	
0	Maize–maize (1 × 0.33 m, 1 plant/hill)	–	6.24	0.66	6.90	–
	Maize–maize (1 × 1 m, 3 plants/hill)	–	6.16	0.49	6.65	–
	Cassava (1 × 1 m)	13.28	–	–	–	–
	Maize (1 × 0.33 m) + cassava (1 × 1 m)	7.05	5.74	–	5.74	1.38
	Maize (1 × 1 m) + cassava (1 × 1 m)	6.44	5.51	–	5.51	1.29
60+30[b]	Maize–maize (1 × 0.33 m, 1 plant/hill)	–	5.72	0.61	6.33	–
	Maize–maize (1 × 1 m, 3 plants/hill)	–	6.34	0.89	7.23	–
	Cassava (1× 1 m)	11.04	–	–	–	–
	Maize (1× 0.33 m) + cassava, (1 × 1 m)	5.92	5.60	–	5.60	1.37
	Maize (1 × 1 m) + cassava (1 × 1 m)	5.82	6.13	–	6.13	1.43
120+30[b]	Maize–maize (1 × 0.33 m, 1 plant/hill)	–	6.06	0.79	6.85	–
	Maize–maize (1 × 1 m, 3 plants/hill)	–	6.12	0.69	6.81	–
	Cassava (1× 1 m)	7.79	–	–	–	–
	Maize (1 × 0.33 m) + cassava (1 × 1 m)	7.50	5.56	–	5.56	1.77
	Maize (1 × 1 m) + cassava (1 × 1 m)	6.06	5.67	–	5.67	1.60

[a]Cassava harvested at 10 months; first season maize variety TZPB and second season maize variety TZE.
[b]30 kg N applied during second season to cassava and TZE maize.

affected by drought during grain filling, which resulted in lower grain yields (Table 2). Despite the lower grain yields, the sole and intercropped maize showed significant responses to nitrogen application. As also observed in the previous year, intercropping with cassava had no effect on maize grain yield.

With later harvest (13 months), cassava root yields were higher in the second year (Table 2). Despite the higher root yields, no significant response to nitrogen application was observed — a reflection of the lower nitrogen requirements of the cassava crop. In the second year, intercropping with maize had no effect on cassava root yields.

At the time of harvest of the intercropped maize, distinct canopy differences were noticed between the sole and intercropped cassava. The sole cassava plants were vigorous, leafy, and showed good visual response to nitrogen in top growth. The intercropped cassava, on the other hand, was etiolated with poor branching smaller foliage. Despite this large difference in canopy at age 4–5 months, the intercropped and sole cassava had comparable root yields (Table 2). Oelsligle et al. (1975) reported similar observations in a nitrogen-response trial with sole and intercropped maize and cassava in Costa Rica. They postulated, on the one hand, that cassava plants in pure stands stored their excess photosynthate in roots during the early to mid part of the crop productive cycle, remaining thereafter relatively inactive metabolically till harvest. On the other hand, intercropped cassava, once released from direct competition with maize, rebuilt its photosynthetic apparatus and stored the bulk of its excess photosynthates in roots during a later part of its growth. Thus, given a sufficient growth period, intercropped cassava can produce yields comparable with those from pure stands.

High LER values are obtained with maize–cassava intercropping. Oelsligle et al. (1975) reported LER values in the range of 2.26–2.94, indicating the high productivity of the maize–cassava mixed cropping system.

CONCLUSIONS

Results from both trials clearly indicate the high productivity of the maize–cassava mixed cropping system. They also suggest that with the improved maize cultivar TZPB and the improved cassava cultivars TMS 30395 and TMS 30572, a maize population of 30 000 plants/ha combined with a cassava population of 10 000 plants/ha is well within the optimum range for maize–cassava intercropping. On relatively fertile soil, nitrogen application will benefit the maize crop more than the associated cassava crop.

CASSAVA LEAF HARVESTING IN ZAIRE

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In Zaire, harvesting cassava leaves for use as a vegetable could increase the total revenue (leaf and root) from the crop by 1.5–6 times, depending on cultivar and on frequency of leaf harvesting. Frequent removal of leaves results in a high incidence of cassava mosaic disease (CMD) and reductions in root and leaf yields. Harvesting leaves once a month provides a high leaf production and returns with low losses in root yield.

La récolte de feuilles de manioc pour l'alimentation pourrait augmenter de 1,5 à 6 fois le revenu total de cette culture au Zaïre, selon le cultivar et la fréquence de la cueillette. Cependant, les cueillettes trop rapprochées peuvent provoquer une attaque sévère de mosaïque et compromettre le rendement de la plante à la fois au niveau des tubercules et celui des feuilles. Une seule récolte de feuilles par mois assure la rentabilité de la culture en permettant une production élevée de feuilles et en réduisant les pertes de tubercules.

Cassava is the most important staple food in Zaire. Production is about 11 Mt, Zaire being the largest producer of cassava in Africa and third in the world after Brazil and Indonesia.

In Zaire, cassava provides about 60% of the average person's daily caloric intake, and its leaves are the basic vegetable, the cheapest and richest source of protein. In addition to consumption by human beings, cassava leaves are used as a nutritionally valuable product in livestock feeds (Hutagalung et al. 1973; Moore 1976).

However, to date there have been few published reports on cassava leaf production. Montaldo and Montilla (1976) reported that harvesting of leaves in Venezuela decreased root production significantly when all mature blades were harvested every 4 months. In Zaire, PRONAM (Programme National Manioc) initiated studies to provide information on how the harvesting of leaves influences cassava foliage production, root yields, disease incidences, and total revenue.

Such information is critical to those who are involved in cassava production, especially in Zaire where leaves and roots are consumed almost daily.

PROCEDURE

Two cassava varieties, Kangu (a local variety grown in Bas-Zaire) and 02864 (a sweet variety developed by INERA), were planted on an alluvial soil deposit at M'vuazi, Zaire, during the growing season 1975–76.

Cassava stakes, 25 cm long, were planted on the flat on 35 m^2 at spacings of 1.00 × 1.00 m. The experimental design was a randomized block with four replications. The four treatments were harvesting:

- Frequently — whenever leaves were mature enough to be used as a vegetable;
- Once a month;
- Once every 2 months; and
- Not at all — the control.

From 5 months after the cassava was planted, leaves that were considered suitable for sale in the local market were harvested from the topmost part of the cassava canopy. We weighed them to estimate leaf production and the revenue of marketable leaves. Scoring for disease, such as cassava mosaic (CMD), cassava bacterial blight (CBB), and cassava anthracnose (CA) was done during the rainy and dry seasons. Fresh root yield was noted after 12 months.

RESULTS

Increased leaf yield was noticed during the rainy period, and leaf production tended to decline during the dry season as well as with increasing frequency of pruning, although variations in rates of decline were observed among the cultivars (Fig. 1).

Compared with monthly harvests, bimonthly harvests, i.e., every 2 months, reduced leaf production by more than 25% to 16.3 t/ha for Kangu

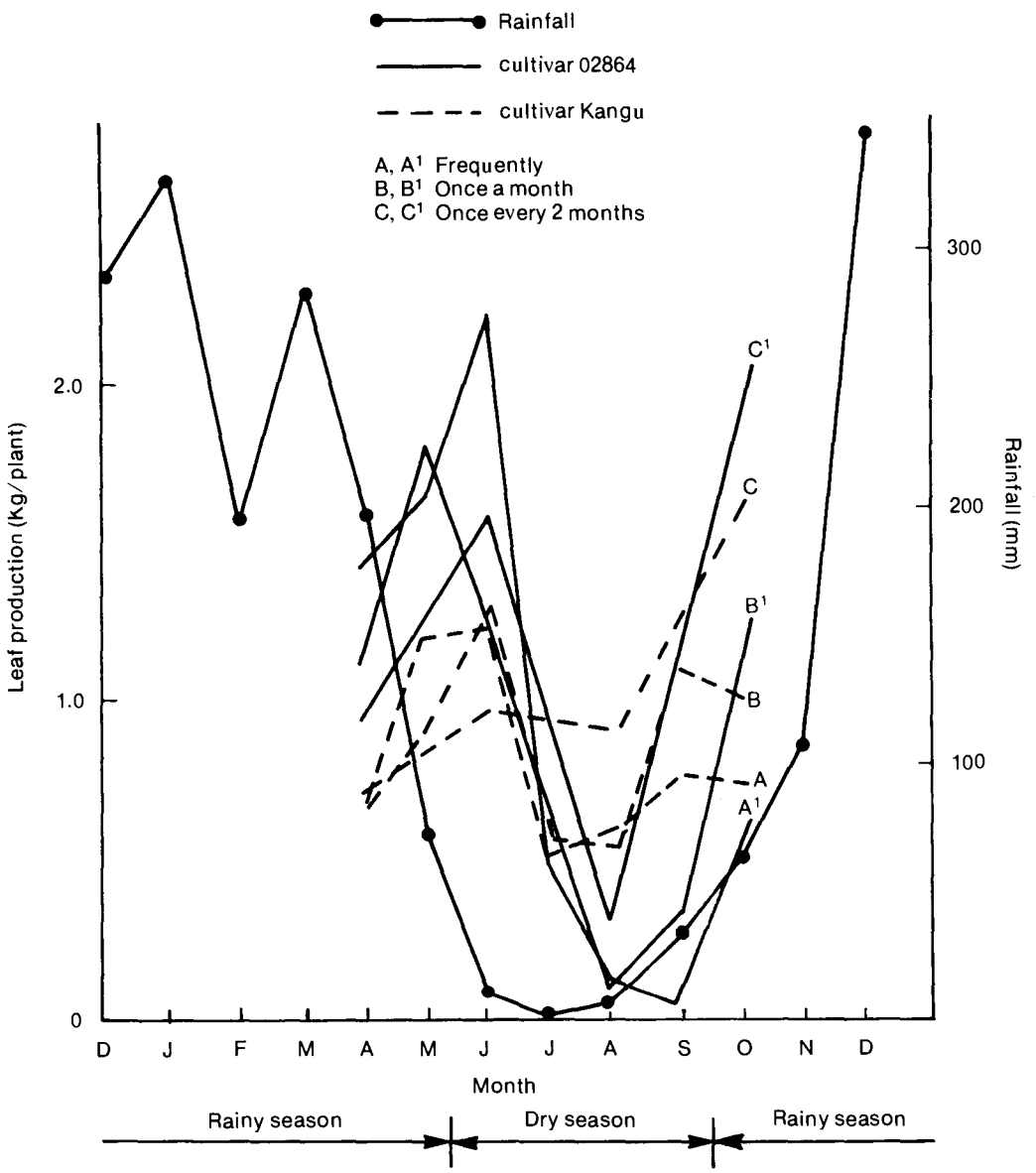

Fig. 1. *Leaf yield of two cassava cultivars and rainfall distribution at M'vuazi, Zaire.*

and 17.6 t/ha for 02864, and harvesting frequently depressed leaf production even more (to 5.7 and 6.9 t/ha). The highest yields in leaves were obtained when leaves were harvested once a month — 22.7 t/ha for Kangu and 24.5 t/ha for 02864.

The more frequently that cassava leaves were harvested, the higher was the incidence of CMD (Table 1); the relationship of frequency of harvest and the prevalence of CBB and CA may not have been consistent throughout the crops' growth because rainfall and humidity are important in the expression of these two diseases (IITA 1975; Terry 1976). Nevertheless, it is noteworthy that there was a decline in anthracnose with increasing frequency of leaf harvest.

Harvesting leaves generally resulted in reduction of root yields compared with the control (14.5 t/ha for Kangu and 30.2 t/ha for 02864), but the extent of reduction varied with the frequency. Frequent harvesting caused significant reductions of 66 and

Table 1. Effect of frequency of leaf picking on the severity of diseases in two cassava cultivars.

Leaf harvest	Kangu						02864					
	May			Sept			May			Sept		
	CMD	CBB	CA	CMD	CBB	CA	CMD	CBB	CA	CMD	CBB	CA
Frequently	5.0	4.8	1.8	4.3	4.0	2.1	4.8	2.5	2.2	3.5	3.8	2.0
Monthly	4.5	2.8	2.2	4.0	3.0	2.2	4.8	2.3	2.2	3.0	2.5	2.8
Every 2 months	3.0	1.8	2.0	4.0	2.0	3.0	2.8	2.0	2.0	3.2	2.0	3.0
Control	3.0	2.2	2.5	2.2	2.0	3.0	2.2	2.2	3.2	3.0	2.0	3.3
Standard error	1.02	1.34	0.30	0.96	0.96	0.50	1.35	0.19	0.55	0.25	0.83	0.55

Table 2. Effect of frequency of leaf picking on revenue (zaires/ha) from two cassava cultivars.[a]

Leaf harvest	Kangu		02864	
	Root revenue	Leaf revenue	Root revenue	Leaf revenue
Frequently	1.47a	5.70a	4.62a	6.90a
Monthly	3.30b	22.70c	7.56b	24.50c
Every 2 months	4.20c	16.30b	10.74c	17.60b
Control	4.35c	–	9.06a	–

[a]The revenues are based on 0.30 Z and 1.00 Z per kg of fresh roots and fresh leaves respectively; means followed by different letters are significant at the 5% level of probability.

49% to 4.9 and 15.4 t/ha for Kangu and 02864, respectively. Monthly harvests reduced root yields to 11.0 and 25.2 t/ha. Limited leaf harvesting was advantageous for 02864, where picking leaves once every 2 months increased root yields by 18.5% over the control.

The revenues of roots from the control were not significantly different from those obtained when leaves were harvested only once every 2 months, but lower revenues were obtained when leaves were harvested frequently or monthly. Revenue from leaves harvested monthly was higher than that obtained when leaves were harvested frequently or every 2 months. Total revenues (leaf and root) from harvesting leaves of 02864 cultivar frequently, once a month, and every 2 months were respectively, 1.6, 5.9, and 4.7 times those of the control, and for Kangu, they were 1.3, 3.5, and 3.1 times the control revenues.

DISCUSSION AND CONCLUSIONS

When leaves are harvested frequently, leaf production, root yield, and plant development and vigour are depressed. Frequent pruning also increases the prevalence of CMD and affects the overall yield and returns from the crop.

Harvesting leaves every 2 months does not affect root yield under the ecological conditions found in M'vuazi. In other words, a cassava field could be used as a source for leafy vegetables without adverse effects on root yields if leaves were harvested at appropriate intervals. Depending on the growth ability of the cultivar, leaf production could increase as a result of harvesting the leaves, the plant increasing its secondary, tertiary, and other branches. Our results suggest that cassava grown for roots can provide a high leaf revenue with little or no loss in root yields.

Where demands for cassava leaves as a vegetable are high, the revenue from the leaves will justify the efforts of breeders to screen for cassava cultivars with high leaf production and the need for fertilization with nitrogen and irrigation during the dry seasons to boost cassava leaf production.

EFFECTS OF LEAF HARVESTS AND DETOPPING ON THE YIELD OF LEAVES AND ROOTS OF CASSAVA AND SWEET POTATO

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I undertook two studies, one on the effects of harvesting leaves of cassava and the other on the effects of detopping sweet potatoes at different times. My findings were that total fresh leaf yield of cassava variety Isunikakiyan was not significantly affected by harvesting frequency of the leaves unlike that of variety TMS 30211. However, compared with plants with unharvested leaves, there was a total fresh root yield decrease of 56–76%, 34–62%, and 15–32% when leaves were harvested at 1-, 2-, and 3-month intervals. Detopping sweet potato shoot tips resulted in 34–42% less shoot yield than did detopping plants at the base of each shoot. Total shoot yield was unaffected when the tips were harvested at 2-, 3-, or 4-week intervals. Tuber yield was less severely reduced when shoot tips were detopped than when they were cut at the base. As the intervals between detoppings decreased, there was a decrease in tuber numbers, individual tuber size, and total yield. The cassava and sweet potato varieties studied reacted differently to leaf harvests and detopping in terms of root and tuber yields. Harvesting cassava leaves at 2- or 3-month intervals and sweet potato shoots at 4-week intervals is recommended for reasonable overall yields.

Le document comprend deux études effectuées à des périodes différentes sur les effets de la récolte des feuilles chez le manioc et chez la patate douce. Dans le cas du manioc, Isunikakiyan n'a apparemment pas souffert de la cueillette régulière de feuilles, contrairement à TMS 30211. Cependant, si on les compare aux autres plantes non défoliées, le rendement en tubercules a diminué de 56 à 76%, de 34 à 62% et de 15 à 32% respectivement lorsque les feuilles ont été récoltées à des intervalles de 1, 2 et 3 mois. Mais la production de tubercules a été moins affectée par la cueillette de bourgeons terminaux que par celle des pousses à la base de la plante. Et plus les intervalles de cueillette de bourgeons terminaux étaient rapprochés plus le nombre de tubercules diminuait. Leur dimension était plus réduite et le rendement total plus faible. La défoliaison ou la cueillette des bourgeons affecte différemment le rendement en racines et tubercules selon les variétés de manioc et de patates douces étudiées. Il est recommandé pour obtenir des rendements raisonnables, de n'effectuer la récolte de feuilles de manioc qu'à des intervalles de 2 ou 3 mois et de 4 semaines pour les pousses de patates douces.

The roots of cassava and sweet potato provide the basic food for many people in the tropics, but the leaves of cassava and young stems, petioles, and laminae of sweet potato are also popular foods for many African and Asian peoples. In addition, livestock feed made from cassava leaves (Cresswell 1978) and the shoots of sweet potato is demanding increasing interest.

Cassava leaves are a good source of protein, vitamins, and minerals. Oyenuga (1968) reported that local Nigerian varieties average 14.7% protein, 8.4% ether extract, and 16.1% total ash. Eggum (1970) found that the amino acid content of leaves of three Nigerian varieties averages 6% lysine, 2% methionine, 11% aspartic acid, 6% valine, 5.5% arginine, and 2.2% tryptophan. Cassava leaf meal is nearly equivalent to alfalfa meal in feed value (Khajarern et al. 1977).

Sweet potato shoots are also nutritionally valuable. Kay (1973) reported that a typical analysis of the tops of 100 g of edible shoot is moisture 87.1 g; nitrogen 0.57 g; ether extract 0.67 g; fibre 1.4 g; ash 1.59 g of which 81.2 mg is calcium, 67.3 mg phosphorus, and 10.37 mg iron. The vitamin content is 3.61 mg carotene, 0.06 mg thiamine, 0.17 mg riboflavin, 0.94 mg niacin, and 25 mg ascorbic acid.

However, Ahmad (1973) and Singh and Chaudhury (1975) have reported adverse effects of leaf harvesting on yields of roots from cassava, and Gonzales et al. (1977) have noted similar effects on tuber yields of sweet potatoes from which the shoots have been regularly harvested. Methods must be developed that allow for the cassava and sweet potato foliage to be harvested and still maintain reasonable root and tuber yields. To this

end, I investigated the effects of frequency of leaf harvests on yields of fresh leaves and roots in two cassava varieties. I also conducted two other studies to investigate the effects of pattern and frequency of detopping on yields of shoots and tubers of sweet potatoes.

MATERIALS AND METHODS

CASSAVA EXPERIMENT

I harvested leaves from the top 30 cm of each branch of two cassava varieties, Isunikakiyan and TMS 30211, by plucking them from the stems at various intervals of time.

A 2 × 4 factorial design was used with treatments arranged in four randomized complete blocks, one factor being the two varieties and the other being the timing of leaf harvests — namely harvests at 1-, 2-, and 3-month intervals or no harvests (i.e., 8, 4, 3, and 0 cuts). Each plot consisted of four ridges 10 m long, with 10 stakes, each 23 cm long, planted at 1-m spacings along the ridge on 17 April 1978. At each leaf harvest, starting from 4 months after planting, the fresh leaf weights of 16 plants in the centre of each plot were recorded.

The plants were harvested for roots 1 year after being planted; the central 16 plants/plot were separated into laminae, petioles, stems, tuberous roots, and the original stake. Each part was weighed, and total and marketable roots were counted; roots with a minimum diameter of 5 cm were regarded as marketable.

Samples from roots, stems, and originally planted stakes were shredded separately and 10 (500-g) subsamples per variety of each plant part were dried in an air-ventilated oven at 65°C for 72 h for dry-matter contents. For laminae and petioles, 100-g samples of each plant part per variety were dried at 65°C for 48 h.

The crop was not irrigated; plots were regularly hand weeded. No fertilizers were applied because cassava is a low-income crop and people who grow it for leaves and roots do not normally apply fertilizers.

SWEET POTATO EXPERIMENTS

Two separate detopping experiments were conducted in 1977 and 1978 at the International Institute of Tropical Agriculture.

In 1977, two sweet potato varieties TIS 2328 and TIS 2154 were subjected to three patterns of detopping. A 2 × 3 factorial design was used with the treatments arranged in four randomized complete blocks, one factor being the two varieties and the other being the pattern of detopping, namely no detopping, detopping the tips (only 25 cm of each shoot tip), and detopping shoots at the base, i.e., 10 cm from ground level.

Each plot consisted of four ridges, each 3.6 m long, with 12 sweet potato slips (cuttings), each 30 cm long, planted at 30-cm spacings along the ridge on 4 May 1977. The crop was rainfed except for 4 h of overhead irrigation applied early for good plant establishment.

The shoots were detopped 48 and 86 days after being planted, and fresh shoot weights of 16 plants in the centre of each plot were recorded. The plants were harvested for tubers 152 days after being planted; and the number and fresh weights of total and marketable tubers were recorded, roots with a minimum diameter of 2.5 cm being regarded as marketable.

In 1978, a field experiment was conducted on the effects of frequency of detopping 25 cm of each shoot tip of two varieties, TIS 2154 and TIS 3030.

A 2 × 4 factorial design with four randomized complete blocks was used, one factor being the two varieties and the other being the timing of detopping, namely no detopping and detopping at 2-, 3-, and 4-week intervals. Slips (cuttings) were planted on 19 April 1978 at the same plot size and plant population as in 1977. The plants were irrigated for 4 h, 13 days after being planted for good establishment. First detopping was at 55 days, and plants were harvested for tubers at 154 days. The same measurements as in 1977 were taken in 1978.

The field plots were hand weeded regularly and an insecticidal spray of 5-ml Rogor 50 and 50-ml Gammalin in 10 litres of water was applied twice to control weevils and other leaf-eating insects. No fertilizers were applied.

RESULTS

CASSAVA

Total fresh-leaf yield of variety Isunikakiyan was not significantly affected by harvesting of the top leaves at 1-, 2-, or 3-month intervals. However, TMS 30211 produced a total of 13.6 and 11.9 t/ha of fresh leaves when harvested at 1- and 2-month intervals, respectively — amounts that were significantly higher than the 7.6 t/ha resulting from leaf harvests at 3-month intervals (Table 1).

Total and marketable fresh root yields of Isunikakiyan showed increases as the intervals between leaf harvests lengthened. Compared with control plants, leaf-harvested plants had decreases of 76, 62, and 15% in total fresh root yield when leaves were harvested at 1-, 2-, and 3-month

intervals, respectively. At each interval, fresh marketable root yields were reduced by about 10% more than was total root yield. Increasing intervals between leaf harvests had a significant effect on the percentage of marketable roots, falling from 78 to 69, 58, and 40 with 0, 3, 4, and 8 harvests. Significantly higher total and marketable root yields were also obtained from TMS 30211 with no leaf harvest than with harvests at 1, 2, or 3 months (Table 1). Compared with control plants, the leaf-harvested plants had decreases of 56, 34, and 32% in total fresh root yields when leaves were harvested at 1-, 2-, and 3-month intervals, respectively. Fresh marketable root yields were reduced by 71, 40, and 42%, respectively, at the same intervals of leaf harvests. Whereas 83% of total fresh root yield was marketable in control plants, 71, 75, and 54%, respectively, was marketable from plants whose leaves were harvested at 3-, 2- and 1-month intervals.

Number of roots per plant and weight per individual root were regarded as components of root yield. Intervals of leaf harvests did not significantly affect the total number of roots produced by either variety. The total number of marketable roots produced by Isunikakiyan was also unaffected by intervals of leaf harvests, but the plants of TMS 30211 with intact leaves produced significantly more marketable roots than plants with leaves harvested at 1- or 3-month intervals. As the intervals of leaf harvests shortened, there was a reduction in the weights of individual roots of both varieties (Table 1).

At final harvest, total dry matter produced by plants of variety TMS 30211 decreased as the time between leaf harvests decreased, and plants with intact leaves produced significantly more dry matter than did those with harvested leaves. The plants of variety Isunikakiyan with leaves harvested monthly produced significantly lower total dry matter than did control plants and plants with leaves harvested at 3-month intervals (Table 1).

The distribution of dry matter in the roots and other plant parts was calculated. The distribution of dry matter to the roots (harvest index) of variety Isunikakiyan decreased as the intervals between leaf harvests decreased. Plants of variety Isunikakiyan with unharvested leaves deposited 29% of total dry matter in the roots, whereas those with leaves harvested at 3-, 2-, and 1-month intervals, respectively, accumulated 24, 16, and 13% of total dry matter in the roots. There was a corresponding increase in dry-matter distribution to the stems and originally planted stakes as the intervals between leaf harvests decreased. Plants of variety Isunikakiyan with unharvested leaves deposited 53% of total dry matter in the stems and 9% in the stakes. Those with leaves harvested at 3-month intervals accumulated 57% in the stems and 9% in the planted stakes; plants with leaves harvested at 2-month intervals had 61% in the stems and 10% in the stakes, whereas those with leaves harvested monthly deposited 66% in the stems and 12% in the stakes.

The percentages of total dry matter deposited in the laminae and petioles were more or less unchanged in plants of both varieties subjected to the various intervals between leaf harvests. At each interval, TMS 30211 plants deposited a greater percentage of total dry matter in the roots and a lower percentage in the stems and original stakes than did Isunikakiyan. The pattern of dry-matter distribution of TMS 30211 subjected to the various leaf harvests was similar to that of Isunikakiyan but was less marked.

SWEET POTATO

When shoots of both TIS 2328 and TIS 2154 were detopped 10 cm from the ground, total yields of fresh shoots were significantly higher than when shoot tips were cut. When shoot tips of TIS 2328 and TIS 2154 were harvested, the shoot yields were 42 and 34% lower than those for detopped plants.

Harvesting the crop for shoots, however, led to a reduction in tuber yield, the extent of which differed between the two varieties (Table 2). Compared with control TIS 2328, there was a decrease of 48% in total fresh tuber yield when shoot tips were cut, and harvesting the shoots at the base resulted in a decrease of 62%. In variety TIS 2154, total fresh tuber yield was decreased by 31% when shoot tips were cut and 50% when shoots were harvested at the base.

Detopping plants of variety TIS 2328 affected the percentage of marketable tubers. When the plant was left intact, 69% of the total tuber yield was marketable, whereas when shoot tips or entire shoots were harvested, the marketable percentages were 55 and 48, respectively. The percentages of marketable tubers from TIS 2154 were 98 for intact plants, 95 for plants with detopped shoot tips, and 94% in plants cut at the shoot base.

The yields of fresh shoots of varieties TIS 2154 and TIS 3030 were not significantly affected when shoot tips were cut at 2-, 3-, and 4-week intervals (Table 3).

Frequency of detopping had a marked effect on total tuber yield. Intact TIS 2154 plants outyielded those detopped at 4-week intervals, whereas those cut at 4-week intervals outyielded plants detopped at 2-week intervals. There was no significant difference in tuber yields of TIS 2154 plants detopped

Table 1. Effects of frequency of leaf harvests on yields of cassava.

Variety	Leaf harvests	Total plant dry weight (g/plant)	Total tuberous root dry weight (g/plant)	Harvest index (%)	Fresh leaf yield (t/ha)	Total roots			Marketable roots		
						Roots/ plant	Fresh yield (t/ha)	Fresh weight/ root (g)	Roots/ plant	Fresh yield (t/ha)	Fresh weight/ root (g)
Isunikakiyan	0	1352	390	28.9	0.0	4.4	14.4	328	1.9	11.2	590
Isunikakiyan	3	1377	330	24.0	4.5	5.1	12.2	240	1.9	8.4	440
Isunikakiyan	4	917	149	16.3	4.1	3.4	5.5	162	0.8	3.2	396
Isunikakiyan	8	715	93	13.0	7.7	3.6	3.5	96	0.6	1.4	239
TMS 30211	0	2298	892	38.8	0.0	9.2	37.3	406	4.7	30.9	657
TMS 30211	3	1590	603	38.0	7.6	8.4	25.2	300	3.3	17.8	392
TMS 30211	4	1526	585	38.3	11.9	9.2	24.6	270	3.8	18.5	488
TMS 30211	8	1179	397	33.7	13.6	9.6	16.6	173	2.3	9.0	540

Table 2. Effect of pattern of detopping on the yields of sweet potato.

Variety	Pattern of detopping	Fresh shoot yield (t/ha)	Total tubers			Marketable tubers		
			Tubers/ plant	Fresh yield (t/ha)	Fresh weight/ root (g)	Tubers/ plant	Fresh yield (t/ha)	Fresh weight/ root (g)
TIS 2328	Whole shoot	44.2	2.8	4.0	49	0.5	1.9	114
TIS 2328	Shoot tips	25.7	3.4	5.5	48	0.5	3.0	181
TIS 2328	None	0.0	4.4	10.6	73	1.2	7.3	184
TIS 2154	Whole shoot	35.6	2.1	12.5	182	1.4	11.8	253
TIS 2154	Shoot tips	23.6	2.2	17.1	235	1.4	16.2	348
TIS 2154	None	0.0	2.2	24.8	339	1.7	24.4	428

at 2- and 3-week intervals. Compared with intact plants, there was a tuber yield decrease of 72, 66, and 51%, when TIS 2154 was detopped at 2-, 3-, and 4-week intervals, respectively.

Intact plants of variety TIS 3030 outyielded those detopped at 4-week intervals, and plants detopped at 4-week intervals outyielded those detopped at 2- or 3-week intervals. There was a fresh tuber yield decrease of 73, 69, and 45% when shoot tips were cut at 2-, 3-, and 4-week intervals, respectively, when compared with the control plants.

At each frequency of detopping, marketable tuber yield of both varieties was reduced slightly more than was the case with total tuber yield. There was a decrease of 76, 68, and 53%, respectively, in marketable tuber yield of TIS 2154 at 2-, 3-, and 4-week detopping intervals when compared with intact plants. The corresponding percentages for TIS 3030 were 76, 72, and 42.

The percentage of marketable tubers decreased with more frequent detopping. Intact plants of variety TIS 2154 had 98% marketable tubers; plants detopped at 4-week intervals had 95%, and those detopped at 3-, and 2-week intervals had 90 and 84%, respectively. In the case of TIS 3030, 96, 93, 87, and 84% marketable tubers were produced from intact plants and from those detopped at 4-, 3- and 2-week intervals, respectively.

Pattern of detopping affected both the total and the marketable yields of tubers produced by variety TIS 2328 but not by TIS 2154 (Table 3). Intact TIS 2328 plants produced significantly more tubers than did plants subjected to the other two patterns of detopping. For each pattern of detopping, variety TIS 2328 produced more tubers per plant than did TIS 2154, but TIS 2154 produced more marketable roots.

Weight per individual root for both total and marketable tubers of variety TIS 2328 was not significantly affected by pattern of detopping, but intact TIS 2154 plants had heavier individual tubers than did plants subjected to detopping (Table 2).

As the frequency of detopping increased, the weight of individual tubers from TIS 2154 was significantly reduced, but there was no change in the number of tubers per plant. In variety TIS 3030, both individual root weights and numbers of tubers per plant decreased as frequency of detopping increased (Table 3).

DISCUSSION

Detopping sweet potato plants at the base of each shoot twice during crop growth resulted in higher shoot yield than did harvesting shoot tips but lower total and marketable tuber yields and size per individual root. If sweet potato is to be grown for both shoots and roots as human food, then it would be better to harvest only shoot tips because the effects on root yields appear to be minimized, and, furthermore, the shoot tips are tender and palatable vegetables.

As the intervals between cassava leaf harvests and sweet potato detoppings decreased, there was a significant decrease in the total and marketable root yields, suggesting that the number of leaf harvests and detoppings should be limited if the crops are to be grown for both leaves and roots.

Total fresh-leaf yield of cassava variety Isunikakiyan was not significantly affected by harvest intervals, and there was no significant difference in root yields between plants with unharvested leaves and those with leaves harvested only every 3 months. Variety TMS 30211 gave almost the same root yields when leaves were harvested every 3 or 2 months but significantly more fresh leaves when harvested at 2- than at 1-month intervals. It is,

Table 3. Effect of frequency of detopping on the yields of sweet potato.

Variety	Frequency of detopping	Fresh shoot yield (t/ha)	Total tubers			Marketable tubers		
			Tubers/ plant	Fresh yield (t/ha)	Fresh wt/ root (g)	Tubers/ plant	Fresh yield (t/ha)	Fresh wt/ root (g)
TIS 2154	None	0.0	2.7	36.9	410	2.2	36.1	493
TIS 2154	Every 4 weeks	20.8	2.3	18.0	235	1.7	17.1	303
TIS 2154	Every 3 weeks	22.2	2.2	12.7	173	1.5	11.4	228
TIS 2154	Every 2 weeks	20.5	2.6	10.4	119	1.4	8.7	185
TIS 3030	None	0.0	4.9	46.5	286	3.5	44.4	381
TIS 3030	Every 4 weeks	21.3	4.6	25.7	168	3.3	23.8	218
TIS 3030	Every 3 weeks	24.0	4.0	14.3	108	2.4	12.5	158
TIS 3030	Every 2 weeks	21.9	3.5	12.7	107	2.0	10.6	158

therefore, recommended that cassava leaves should be harvested at 2- or 3-month intervals to ensure reasonable yields of both leaves and roots.

Harvesting sweet potato shoot tips at 4-week intervals produced as much fresh shoots as detopping at 2- or 3-week intervals, but tuber yield was less affected. Harvesting shoot tips at 4-week intervals is, thus, recommended for reasonable yields of both shoots and tubers.

The two cassava varieties reacted differently to leaf harvests in terms of root yields, which were reduced more in Isunikakiyan than in TMS 30211 perhaps because the latter produces many more leaves. Pattern of detopping sweet potato affected the total number of roots produced by variety TIS 2328 and TIS 3030, but the number of roots produced by TIS 2154 was not significantly affected by frequency of detopping.

Efforts to select cassava and sweet potato for both foliage and root production should focus on high-yielding varieties whose roots and tubers are likely to be less affected by leaf harvests or detoppings.

Intervals of leaf harvests significantly affected the size of individual cassava roots but not the total number produced, i.e., the size of roots contributed more to yield than their numbers, as Williams (1974) has also reported. Because the first leaf harvest was not taken until 4 months after planting, it seems that root numbers were determined early in growth. Hunt et al. (1977) noted that the number of cassava storage roots was generally determined early in growth, and Wholey and Cock (1974) noted that the number of thickened roots per plant remained fairly constant after 3 months of growth in all but 2 of 13 cassava varieties.

Dry-matter distribution to the roots (harvest index) of cassava variety Isunikakiyan decreased with more frequent leaf harvests, and there was a corresponding increase in dry-matter in the stems and original stakes. More frequent leaf harvests led to keener competition between the roots and shoots for assimilates, and, as Waring (1970) observed, shoot systems appear to have the advantage when there is such competition.

The decrease in cassava and sweet potato root and tuber yields with more frequent leaf harvests and detoppings may be ascribed to the reduced effective photosynthetic area. Hunt et al. (1977) noted that the deposition of starch and, perhaps, the proliferation of parenchyma cells of roots are reduced if the supply of carbohydrates is curtailed, as it is when much leaf and stem material is removed.

In countries where cassava and sweet potato foliage is used as food and feed, there is a distinct possibility that the foliage and roots could be treated as two distinct crops, the roots rich in carbohydrate and the foliage rich in protein, vitamins, and minerals. These results show that reasonable tuberous root yields can be achieved if optimum leaf harvest or detopping interval is determined and adopted.

METABOLISM, SYNTHETIC SITE, AND TRANSLOCATION OF CYANOGENIC GLYCOSIDES IN CASSAVA

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We investigated the pathway of linamarin biosynthesis in cassava by vapour administration of ^{14}C-labeled precursors to cassava leaves. The incorporation of these precursors and of labeled valine administered by solution uptake was consistent with a pattern of linamarin biosynthesis established for other plants. It involves the reaction sequence through valine, isobutyraldoxime, isobutyronitrile, and 2-hydroxyisobutyronitrile. Administration of [^{14}C]valine to various organs of a cassava plant indicated that the leaf petioles, midribs, and shoot apex synthesize linamarin more efficiently than does the woody stem or the roots. No direct relationship was found between endogenous linamarin content and the organ's apparent ability to synthesize linamarin from exogenous valine. However, the low ability of leaf-blade tissues, root peels, and the edible flesh to incorporate valine into linamarin could be due to more active competing pathways removing the exogenously administered valine. We also investigated the translocation of linamarin in the cassava plant by following the path of leaf-synthesized linamarin translocated from the leaf to other parts of the plant. In both tuberous and nontuberous plants, a rapid loss of [^{14}C]linamarin has been shown to be due to translocation from the leaves. However, a residual component of [^{14}C]linamarin remained in the leaves. In senescing leaves, a continuous loss of both ^{14}C-labeled and endogenous linamarin occurred and left almost no residual component. This finding was attributed to both translocation and turnover. Translocated linamarin was distributed to all parts of the plant. An apical direction of linamarin distribution exists in the nontuberous plants, whereas root-directed linamarin translocation prevailed in the root plants. Leaf senescence apparently enhances linamarin translocation to the roots. We found there was little turnover of freshly synthesized [^{14}C]linamarin in detached leaves and root tissues. However low recoveries of [^{14}C]linamarin in the whole-plant translocation experiments suggest that active turnover is occurring during translocation or in certain tissues.

Essai sur la filière de la biosynthèse de la linamarine par la vaporisation de précurseurs appelés ^{14}C sur des feuilles de manioc. L'incorporation de ces précurseurs et de la valine administrés en solution correspond au modèle de biosynthèse de la linamarine établi chez d'autres plantes. Il comprend la suite des réactions à la valine, l'isobutyraldoxine, l'isobutyronitrile, et le 2-hydroxyisobutyronitrile. La vaporisation de valine sur les organes d'une plante de manioc a révélé que les pétioles, la nervure et l'apex des feuilles synthétisaient plus efficacement la linamarine que les tiges ligneuses ou les racines. On n'a trouvé aucune relation entre le contenu endogène de linamarine et la capacité apparente de l'organe à la synthétiser à partir de la valine. Cependant, le peu d'aptitude des tissus du limbe, des écorces des racines et de la chair comestible à incorporer la valine en linamarine pourrait provenir de l'existence de modes concurrentiels plus actifs qui neutraliseraient la valine administrée de l'extérieur. L'étude a aussi porté sur la translocation de la linamarine dans la plante en suivant la circulation de la feuille aux autres organes. Chez les plantes tubéreuses et non tubéreuses, cette translocation se traduit par une perte rapide de linamarine bien que les feuilles en retiennent une certaine quantité. Les feuilles âgées perdent continuellement la linamarine ^{14}C endogène presque sans conserver de résidu, phénomène attribué à la translocation et à la transubstantiation. Par la translocation, la linamarine a été distribuée dans tous les organes de la plante. Chez les plantes non tubéreuses, on a observé que la distribution de la linamarine suivait une direction apicale alors que chez les tubéreuses, la translocation était dirigée vers les tubercules. Il semble que la sénescence des feuilles favorise la translocation vers les racines. Les feuilles et les tissus des racines prélevés avaient peu transformé la linamarine qu'ils venaient de synthétiser. Cependant, la faible récupération de linamarine dans l'ensemble de la plante laisse envisager l'existence d'un phénomène actif de transubstantiation en cours de translocation ou dans les tissus mêmes.

Linamarin and lotaustralin, the cyanogenic glucosides of cassava, occur in all known cassava varieties and in all tissues of the plant. Possible pathways for cyanogenic glucoside biosynthesis

have been reported. Nartey (1968) reported a significant conversion of valine and isoleucine into linamarin and lotaustralin, respectively, by etiolated cassava seedlings. The actual biosynthetic pathways have not as yet been elucidated. The increasing role of cassava as feed and food intensifies the importance of an understanding of the metabolism of the cyanogenic glucosides contained in the plants. Participants at a conference on cassava toxicity in 1973 (Nestel and MacIntyre 1973) recommended such an investigation as useful to researchers screening and breeding for acyanogenic or low cyanogenic cassava. This paper reports on work done on linamarin biosynthesis in cassava, identifying the major sites of linamarin biosynthesis in the plant and investigating the possibility of translocation of linamarin from synthetic sites to other parts of the plant. The biosynthetic pathway was investigated by administration of some of the volatile precursors of linamarin, isobutyronitrile, isobutyraldoxime, and 2-hydroxyisobutyronitrile by a new technique in which the leaves were allowed to take up the precursor vapour in an enclosed glass chambre. Solution administration of L-[U-^{14}C]valine to various organs of the plant was used to investigate the biosynthetic sites. We labeled [^{14}C]linamarin in leaves with 2-hydroxy [I-^{14}C]isobutyronitrile vapour and followed the change in labeled linamarin content in the leaf and the distribution of linamarin to other parts of the plant.

EXPERIMENTAL PROCEDURE

SOURCE OF PLANT MATERIALS

Cassava seeds of unspecified varieties from Centro Internacional de Agricultura Tropical (CIAT), Cali, Colombia, were germinated in peat beds under glasshouse conditions (18–35°C and 75–90% relative humidity). Stakes of varieties Bega, Manioke, and Navolau obtained from the Ministry of Agriculture, Konorovia Research Station, Nansori, Fiji, were propagated in plastic troughs on peat beds. We obtained rooted sections of cassava either by using the shoot-apex method of Wholey and Cock (1975) or by suspending stakes in aerated water in free draining sand under mist. Rooted shoots or stakes were grown in solution culture or gravel culture nourished by the nutrient solution described by Forno et al. (1973).

SOURCE OF LABELED COMPONENTS

L-[U-^{14}C]valine was obtained from the Radiochemical Centre, Amersham, England. [I-^{14}C]isobutyronitrile (336 μCi/mmol) was prepared by a modification of the method by Smiley and Arnold (1960). The preparation and purification of the labeled compound are described elsewhere (Bediako 1977). 2-hydroxy[I-^{14}C]isobutyronitrile (262 μCi/mmol) was prepared by a modification of the method of Cox and Stormant with [^{14}C]NaCN and acetone. We purified the labeled cyanohydrin mixture by bubbling through it a gentle stream of nitrogen gas.

[U-^{14}C]isobutyraldoxime (0.848 μCi/mmol) was prepared by the action of hydroxylamine and isobutyraldehyde prepared from valine. The labeled oxime was purified on a gas–liquid chromatography (GLC) column at 110°C.

[I-^{14}C]linamarin was prepared by the administration of 2-hydroxy[I-^{14}C]isobutyronitrile to flax (*Linum usitatissimum*) seedlings. After standing overnight in illuminated chambres at 21°C, the seedlings were thrice extracted with 80% boiling ethanol, concentrated, and chromatographed on Whatman no. 3 mm paper with butanol saturated with water as solvent. The linamarin zone was eluted and frozen. Rechromatography of the eluate followed by elution and counting showed that the extract was radiochemically 80% pure. Linamarase was prepared by the method of Coop (1940).

ANALYTICAL METHODS

Plant materials were extracted in boiling 80% ethanol; insoluble residues were blended and reextracted in triplicate. Combined extracts were stored in a dark room at room temperature or reduced to dryness under vacuum at 50°C, the residues taken up in 20% propanol and stored at 0°C.

Paper chromatography and, thin layer chromatography (TLC)–electrophoresis were used to separate cyanogenic glucosides from other labeled compounds. Linamarin and lotaustralin were detected on chromatograms. [^{14}C]linamarin was estimated from eluates of chromatographic bands by enzymic hydrolysis followed by HCN trapping in alkaline solution and its assay by a colorimetric or potentiometric method. A gas chromatographic technique was also developed for linamarin assay. The method involves preparing TMS derivatives of linamarin and lotaustralin and assaying them on a Varian aerograph 1440 connected to an electron digital integrater and recorder.

We located ^{14}C-labeled compounds on chromatographic strips using a windowless radiochromatogram scanner. Radioactive compounds were detected after TLC–electrophoresis by radioautography with film exposure times up to 4 weeks. Radioactive spots or bands on chromato-

grams were eluted into scintillation vials. Scintillation mixture (1:2 Triton–Toluene solution containing 6 g Omniflour/litre) was added to sample eluates and ^{14}C activity determined with either a liquid scintillation spectrometer (Packard Tricarb 2002) with a wide and narrow window or a liquid scintillation system (Searle) with a teletype paper-punch connection.

Administration of Labeled Precursors

We detached leaf petioles under water and scalded the cut end briefly in hot water to arrest latex exudate. [^{14}C]valine was fed to the leaf by solution uptake through the cut end of the petiole. Then, the leaves were stood in beakers of water overnight at 21°C.

The volatile precursors [I-^{14}C]isobutyronitrile, 2-hydroxy[I-^{14}C]isobutyronitrile, and [U-^{14}C]isobutyraldoxime were administered to leaves by vapour uptake in a glass feeding chambre. The chambre consisting of a thick-walled circular glass dish (2 × 21 cm) with a ground rim was inverted over a leaf supported on a base glass plate. The leaf petiole passed through a side groove on the rim of the plate and a magnetic stirrer inserted in the chambre allowed vapours to be evenly circulated throughout the feeding period. The feeding chambre was made airtight with a layer of silicone gum laid between the dish and the base plate and tightly clamped down. Precursor solution was fed through an inlet septum on to the inner glass plate. The oxime and nitrile readily vapourized, but heat was required to vapourize the hydroxynitrile droplet. After various feeding times, residual vapours were trapped by water displacement into a 1 M NaOH solution. We recovered chambre washings to estimate precursor vapour uptake.

Administration of [^{14}C]Valine to Root Cores and Peels

Root and peel tissues were fed with L-[U-^{14}C] valine by vacuum infiltration. The cores were punched from the edible portion and strips of peels were cut out after the outer corky layer was removed.

Results and Discussion

Pathway of Linamarin Biosynthesis

We administered ^{14}C-labeled linamarin precursors primarily to ascertain the suitability of the various precursors for subsequent studies on translocation and biosynthetic activity of different tissues. The results are of interest in connection with the pathway of linamarin biosynthesis (Table 1). The incorporation of the volatile precursors into linamarin in leaves from four different varieties was significant and was similar to that obtained for incorporation of valine. The results indicate that these volatile substances are efficient precursors of linamarin in cassava leaves. The data are consistent with the pathway of linamarin biosynthesis involving a reaction sequence from valine through isobutyraldoxime, isobutyronitrile, and 2-hydroxyisobutyronitrile to linamarin. This pathway has been demonstrated in *Linum* sp. by solution administration of labeled precursors. Enzymic investigation of a similar pathway has been reported in *Sorghum bicolor* by Conn and his co-workers. The involvement of analogous intermediates in this pathway suggests that the general pathway of cyanogenic glucoside biosynthesis is common in most cyanogenic species including cassava. It may be necessary in future investigations to examine the possible existence of an alternative pathway as well.

Such a study could involve the administration of ^{14}C-labeled precursors such as 2-hydroxyisobutyraldoxime in conjunction with the detection of relevant biosynthetic enzymes.

Sites of Linamarin Synthesis in Cassava

The levels of cyanogenic glucosides in cassava tissues do not necessarily indicate which organs are responsible for the production of the cyanogenic glucoside. Table 2 presents data on incorporation of ^{14}C from valine into linamarin. Radiochromatogram scans of the ethanol extracts indicate that administered [^{14}C]valine was extensively metabolized in all tissues. The petiole tissues gave by far the highest percentage incorporation. The values for leaves, upper stem, and shoot apex were similar and were considerably higher than were those for the lower stem and underground tissues — the roots.

Linamarin Biosynthesis in the Petiolate Leaf System

The experiments indicated that the leaves, petioles, and shoot apices are much more active in converting valine into linamarin than are mature stem and underground parts. Thus for follow-up investigations, we chose tissue systems showing large differences in percentage incorporation — the petiolate leaf and the root.

In our feeding experiments, labeled leaves were harvested at 0.5-, 4-, and 24-h intervals and dissected into petioles, midribs, and blade sections.

Table 1. Incorporation of precursors into linamarin in cassava leaves.

Cassava variety	Precursor	Treatment (μCi)	[^{14}C]linamarin		% ^{14}C incorporation
			μCi	SA[b]	
Manioke	Valine	0.954	0.164	5.2	17.2[a]
Navolou	Valine	0.700	0.070	2.0	12.5[a]
A	Valine	1.000	0.091	3.3	11.6[a]
Bega	2-OH-isobutyronitrile	3.820	0.790	13.6	20.6
Manioke	Isobutyronitrile	11.300	0.190	7.9	15.9
Manioke	Isobutyraldoxime	0.610	0.150	6.0	24.9

[a]Corrected for loss of carboxyl carbon.
[b]SA = specific activity (μCi/mmol).

Each tissue was then analyzed for [^{14}C]linamarin (Table 3). The time-course analyses showed that all the tissues of the leaf system incorporate [^{14}C]valine into [^{14}C]linamarin, although incorporation in leaf blade is very low. A high level of incorporation (35–57%) was attained in the leaf petioles. Such high incorporations are comparable only to the 48% incorporation of [^{14}C]valine into linamarin by *Linum usitatissimum*. In the midribs about 20% ^{14}C was incorporated into linamarin after 24 h — a lower rate than was found in the petioles but considerably higher than the 2% value attained in the leaf blades. The very low incorporation levels in the blade tissues could be due to a low biosynthetic capacity of the mesophyll tissue or to the transformation of much of the precursor into other substances before it reaches this tissue. However, similar low synthetic values were observed when the leaf blade was uniformly vapour-fed with 2-hydroxy[I-^{14}C]isobutyronitrile.

Endogenous linamarin in the blades was 11–17 mmol/g and that of the midribs was 31–33 mmol/g fresh weight. These values are higher than that of the petioles (6–8 mmol/g). Thus there seems to be no simple relationship between linamarin levels and biosynthetic activity. Physiologic factors within the leaf tissues may be a contributing factor. The ability of each tissue to store endogenously synthesized linamarin may be greater within the blade and midrib than in the petioles.

Biosynthesis by Root Tissues

The maximum values for incorporation of [^{14}C] valine into linamarin by both the root core and the root peels were low. The cores incorporated about 0.1%; the peels, about 1–2%. Despite these low levels of ^{14}C incorporation, the endogenous linamarin level in the peels was almost as high as in the leaves. The peel, like the leaf blade, may accumulate much of the linamarin it synthesizes. Nevertheless, much of the root linamarin may come from aerial organs of the plant as indicated by the translocation experiments.

Translocation of Linamarin in Cassava

The translocation of linamarin in cassava has scarcely been investigated. De Bruijn carried out

Table 2. Incorporation of valine into linamarin by cassava tissues.

Plant section	L–[U–^{14}C]valine		[^{14}C]linamarin		% ^{14}C incorporation
	μmol	SA[b]	μCi[a]	SA[b]	
Shoot apex	1.0	993	0.160	4.3	16.1
Upper leaves	2.0	496	0.088	2.5	8.9
Lower leaves	2.0	496	0.067	2.4	6.8
Upper leaf petioles	3.0	333	0.623	97.3	62.3
Lower leaf petioles	3.0	333	0.487	55.3	48.7
Upper stem	1.0	993	0.137	4.4	13.1
Lower stem	1.0	993	0.009	0.4	0.9
Primary roots	1.0	2000	0.040	71.4	2.4
Tuberous roots (plus peels)	3.0	333	0.063	1.1	6.3

[a]Corrected for an assumed loss of ^{14}COOH from L–[U–^{14}C]valine.
[b]SA = specific activity (μCi/mmol).

Table 3. Incorporation of [^{14}C]valine into linamarin by leaf tissues.

Leaf section	Metabolic time (h)	[^{14}C]linamarin		
		μmol/g	SA[a]	% ^{14}C in section
Basal petiole	0.5	8.65	3.1	4.4
Distal petiole	0.5	14.00	0.9	4.8
Midribs	0.5	33.00	0.2	2.0
Blade	0.5	15.20	0.2	0.8
Basal petiole	4.0	6.8	12.5	34.9
Distal petiole	4.0	6.9	19.7	57.1
Midribs	4.0	31.1	0.8	12.3
Blade	4.0	14.0	0.6	1.8
Basal petiole	24.0	7.6	16.6	41.6
Distal petiole	24.0	8.2	7.9	21.9
Midribs	24.0	32.8	1.2	20.2
Blade	24.0	17.0	0.7	2.1

[a]SA = specific activity (μCi/mmol).

stem ringing experiments on cassava and reported accumulation of cyanogenic glucosides above the point of incision. Therefore, we investigated the possibility that translocation of linamarin contributes to the endogenous linamarin in the root system. Specifically labeled linamarin was synthesized in situ in the leaf system. The ability of cassava leaves to synthesize linamarin from volatile precursors made it possible for us to administer 2-hydroxy[I-^{14}C]isobutyronitrile directly to an undamaged leaf still attached to the plant. Thus, we were able to follow the disappearance of the labeled linamarin from the fed leaf and its appearance in other tissues with minimum disturbance to the plant.

The time course of changes of [^{14}C]linamarin was followed in attached leaves of various plants by disc analysis, which provided a general indication of linamarin removal from leaves. Preliminary time-course analysis on detached and attached leaves indicated that linamarin breakdown alone did not account for the amount that it decreased in intact leaves.

The time-course patterns indicated a high rate of [^{14}C]linamarin removal from the leaf immediately after synthesis up to 69 h, after which the activity remained almost constant. This trend was found for upper and lower, fully expanded green leaves. Similar biophasic patterns of translocation have been reported for [^{14}C]photoassimilates in corn, sugar beets, and soybean.

The rates of [^{14}C]linamarin translocation from the leaves, however, differed between leaves of tuberous and nontuberous plants and also according to the age or position of the leaf on the plant. On nontuberous plants, the rate at which the lower leaves lost linamarin (as indicated by the time until

Table 4. Distribution (% of initial [^{14}C]linamarin synthesized in source leaf) of translocated linamarin in cassava plants.

Plant organ	Nontuberous plants		Tuberous plants	
	Upper leaf	Lower leaf	Fresh leaf	Senescing leaf
Tubers	–	–	2.4	6.0
Primary roots	0.1	0.2	0.7	0.4
Lower stem	0.2	0.3	2.2	5.3
Upper stem	0.3	0.2	0.7	0.5
Upper leaves	0.3	0.3	0.7	4.9
Lower leaves	ND[a]	ND[a]	0.7	0.5
Source leaf petioles	1.0	0.7	0.2	0.5
Source leaf	14.1	13.8	24.5	0.5
%[^{14}C]linamarin recovered	16.0	15.5	31.4	18.1

[a]ND = not detectable.

activity dropped to 50% of its initial level) was twice as great as the rate of an upper leaf.

The overall kinetic pattern suggests that some of the linamarin synthesized in the leaf is transferred into an immobile pool (after 96 h) from which it can be translocated only very slowly. This immobile pool could be in the cell vacuoles of the leaf-mesophyll tissue. Saunders et al. demonstrated that up to 90% of dhurrin synthesized in young *Sorghum bicolor* seedlings was located in the cell vacuoles. A similar accumulation in the cell vacuoles probably accounts for the slow phase, whereas the initial fast phase may be attributed to rapid loss from a more accessible pool in the plant cells.

An interesting finding of the time-course study was the apparently higher rate of [^{14}C]linamarin translocation from leaf blades of immature nontuberous plants than from the blades of tuberous plants. It appears that the presence of tuberous roots, which might be expected to constitute an effective "sink" does not increase the rate of linamarin translocated from individual leaves.

Translocation of freshly synthesized [^{14}C]linamarin proceeded in normal green leaves, whereas the endogenous linamarin levels remained virtually unchanged. This finding could be interpreted as indicating a steady condition between synthesis and translocation in the leaf tissues. In contrast to the situation in nonsenescing leaves, the senescing leaf blade showed a continuous loss of both endogenous and freshly synthesized [^{14}C]linamarin with the same initial rate. Similar losses of [^{14}C]photoassimilates have been reported on senescing leaves of *Beta vulgaris*.

The mature and immature cassava plants whose attached single leaves had been selectively labeled with [^{14}C]linamarin were harvested after 7 days, divided into various parts, extracted, and analyzed for [^{14}C]linamarin and endogenous linamarin. Because of turnover factors, [^{14}C]linamarin recoveries did not provide a quantitative assessment of the total linamarin translocated from the source leaf but were indicative of the general pattern of "source–sink" relationships between the leaves and other organs and tissues.

Mature green leaves retained about 80% of the total [^{14}C]linamarin recovered from the whole plant. There was not much difference in recoveries from upper and lower leaves or from tuberous and nontuberous plant leaves (Table 4). In marked contrast to this high retention, senescing source leaves retained only 0.5% of the initial [^{14}C]linamarin. By measuring total linamarin levels in attached and detached leaves undergoing senescence, we demonstrated that the loss of linamarin during senescence was attributable to both linamarin turnover and translocation.

In the young nontuberous plants, leaves above the source leaves contained a significant proportion (14–16%) of the translocated linamarin recovered. Thus, in young, nontuberous plants there is a predominantly upward translocation from older leaves to young leaves and shoot apices. The distribution of translocated linamarin in tuberous plants, however, appears to be directed toward the basal organs of the plant. After 7 days of translocation, the tuberous plants gave higher recoveries of [^{14}C]linamarin in the lower stem and roots than in other organs of the plant. Translocation from a senescing leaf to the root system was higher than it was from a nonsenescent leaf. Thus, although the presence of tuberous roots in cassava does not increase the rate of [^{14}C]linamarin translocation from an individual leaf, it does influence the general distribution of translocated [^{14}C]linamarin in the plants.

In translocation experiments using [^{14}C]CO_2 to label photoassimilates in tuberous cassava plants, Hume (1975) reported that 4.4% of the initial [^{14}C]photoassimilates were recovered from the roots after 7 days of translocation and 38% were recovered in the labeled leaves. Despite the varietal and cultural differences of the cassava plants used by Hume and in this experiment, his values are not very different from our observations. This fact suggests that linamarin and products of CO_2 assimilation in cassava are simultaneously translocated from leaves to the roots.

LOSS OF HYDROCYANIC ACID AND ITS DERIVATIVES DURING SUN DRYING OF CASSAVA

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The disappearance of cyanide (CN) and its derivatives from cassava slices, obtained from both "sweet" and "bitter" roots, during sun drying in black and colourless polythene bags, respectively, was studied. In all the experiments, CN was lost progressively with time, most of it within the first 8 h, during which time 46–58% free and 69–74% bound CN disappeared from the "bitter" variety and about 74% of bound CN disappeared from the "sweet" cultivar. The differential losses of bound CN between cultivars in both black and colourless containers, after the initial 16 h, were minimal (1–8%) and comparable in all cases suggesting optimal hydrolytic activity of the β-glucosidase, linamarase. In general, loss of free CN from sweet root slices within each of the initial two 8-h periods of sun drying was much lower (33–37%) than for the bitter variety, presumably as a result of the formation of more cyanohydrins in the sweet cultivar. Our results suggest that a more rapid loss of free CN occurs during sun drying of cassava in black containers. Our findings are discussed in relation to sun drying of cassava roots by direct solar radiation or by black body radiation of solar energy, particularly during atmospheric conditions of high humidity, low temperature, and cloudiness.

Étude sur l'évaporation de l'acide cyanohydrique (HCN) et de ses dérivés dans des tranches de manioc doux et amer placées dans des sacs polythène transparents et noirs pour les faire sécher au soleil. Dans chaque essai, presque tout le contenu d'HCN a progressivement disparu au cours des huit premières heures, de façon progressive mais avec des temps morts, soit de 46 à 58% et de 69 à 74% chez les variétés amères et d'environ 74% chez le manioc doux. Après 16 heures, la différence entre le pourcentage de réduction d'HCN des tubercules mis dans les sacs noirs et transparents était minime et semblable dans chaque cas, ce qui permet de suggérer l'action hydrolithique optimale de la linamarase β-glucosidase. En général, la perte d'HCN au cours des deux premières périodes de 8 heures de séchage au soleil était plus faible chez le manioc doux que chez le manioc amer (33-37%), probablement parce que le premier en contient plus que le second. Les résultats des études permettent d'avancer que les sacs noirs sont plus performants. L'exposé des travaux porte sur le séchage au soleil des racines de manioc, par radiation directe ou convexion dans un sac noir, spécialement dans des conditions d'ennuagement, de basses températures et de forte humidité.

Cassava roots are an important staple food in the tropics. However, they contain cyanogenic glycosides, linamarin and lotaustralin, which produce hydrocyanic acid (HCN) when they come in contact with the endogenous enzyme linamarase. The reaction is initiated when the root is crushed or the cellular structure is otherwise damaged (Conn 1973).

Thus, the utilization of cassava roots for both human and animal nutrition is limited by the presence of these glycosides. As a result, the roots have to be processed by methods (Coursey 1973) that reduce their toxicity and improve their palatability. The traditional methods include drying, soaking, boiling, and fermenting whole or fragmented roots; all of these processes reduce the total cyanide content of the material.

In Nigeria, sun drying of cassava (root slices, chips, flour) is one of the popular traditional processing methods. The materials are spread out, usually on mats, concrete floors, or disused portions of main roads, and left in the sun to dry gradually with occasional turning. The amount of cyanide that is lost from the materials depends on such factors as shape and size of fragments (Thanh and Lohani 1978) and relative humidity, air temperature, and wind velocity (Rao and Cock 1973), all of which affect drying time.

In our investigation, we studied the disappearance of CN and its derivatives from slices of cassava roots of both "sweet" and "bitter" varieties during sun drying in black and colourless containers. The cyanide in cassava occurs as cyanogenic glycosides (bound cyanide), HCN (free cyanide), and acetone cyanohydrin (Conn 1969), the last of which is unstable (Cooke 1978). We determined the differential effects of sun drying on total, free, and bound cyanide, using the sensitive assay method of Cooke (1978).

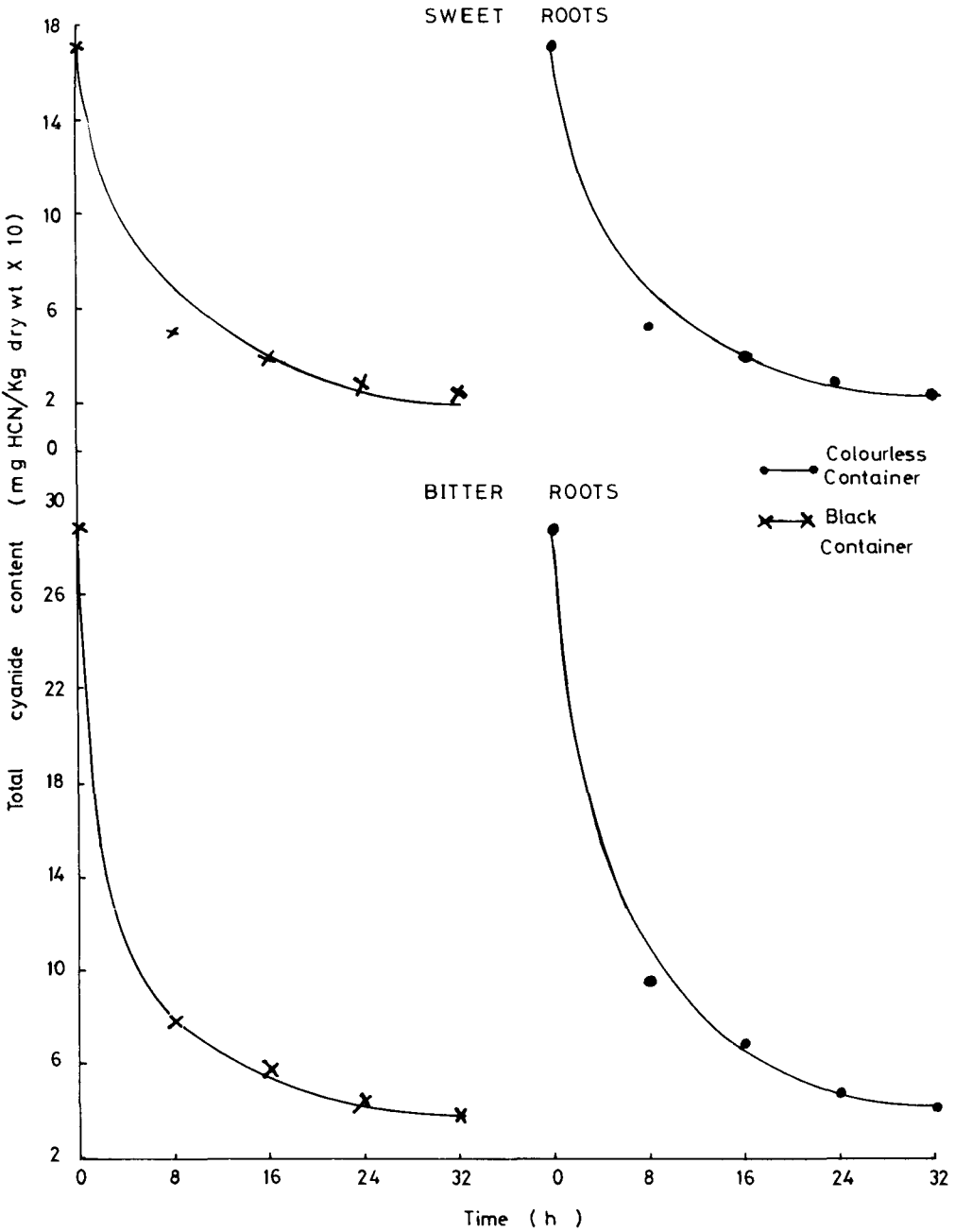

Fig. 1. *Release of hydrocyanic acid in cassava roots during sun drying.*

MATERIALS AND METHODS

Cassava roots (bitter and sweet cultivars) were obtained by courtesy of the Root and Tuber Improvement Programme of the International Institute of Tropical Agriculture. The roots were peeled by hand within 1 h of harvest and chipped into slices (35 ± 14 mm × 6.9 ± 1.2 mm × 5.8 ± 1.3 mm) with a 9-inch (23-cm) vegetable slicer and assembly. Batches from each variety of cassava were thoroughly mixed and sieved so that all chip fragments were eliminated.

Table 1. Differential losses (%) of cyanide by sun-dried cassava in black and colourless containers.

Cassava variety	CN	Black polythene					Colourless polythene				
		0 h	8 h	16 h	24 h	32 h	0 h	8 h	16 h	24 h	32 h
Bitter	Free	0	58	76	80	86	0	46	73	79	85
	Bound	0	74	81	85	87	0	69	77	84	85
Sweet	Free	0	37	69	84	85	0	33	68	83	82
	Bound	0	74	78	84	86	0	73	77	82	85

Random samples of root slices were immediately homogenized in orthophosphoric acid and cyanide contents of aliquots determined; others were bagged in black and colourless polythene containers and left in the sun from 10:00 h to 18:00 h daily. The polythene bags were perforated with tiny holes and their open ends securely tied. Samples were taken after 8, 16, 24, and 32 h of sun drying for cyanide determination, and the test materials were stored at 4°C in a refrigerator after sun drying.

RESULTS AND DISCUSSION

Our results showed that the total cyanide content of cassava chips was reduced progressively (Fig. 1) during sun drying. The mean total, free, and bound cyanide contents of unprocessed cassava slices were 287.21, 26.77, and 260.44 mg CN/kg dry weight, respectively, for the bitter roots and 170.99, 15.29, and 155.70 mg CN/kg dry weight for the sweet variety. The rate of loss of cyanide within the first 8 h was higher for the bound cyanide than for the free form (Table 1), presumably as a result of optimum autolytic hydrolysis of the cyanogenic glycosides during that period. This view is supported by the minimal (1–8%) differential losses of bound cyanide occurring between cultivars in both black and colourless containers after this peak period.

However, loss of the free cyanide was more gradual and, in particular, was very slow from root slices derived from the sweet cultivar. This varietal difference in the rate of loss of free cyanide may be related to the formation of larger quantities of HCN adjuncts in the sweet variety. Such adjuncts would presumably be unstable and would liberate HCN slowly. For example, Ketiku and Oyenuga (1970) have reported on the formation of cyanohydrins from a combination of simple sugars, including hexoses, and free cyanide in freshly grated cassava.

In general, a more rapid loss of free cyanide was recorded in cassava root slices sun dried in the black containers (Table 1). This finding was expected because a black body (unlike a nonblack body) absorbs solar radiation and maximally maintains temperature.

The intensity and quality of black-body radiation during and after sun drying are a function of temperature (Starling and Woodall 1963). Sun drying in or on a black body, therefore, has an advantage over direct solar radiation because it enhances solar radiation during atmospheric conditions of low temperature, high humidity, and cloudiness and because a black body retains heat for a longer time after the sun has set than does a body of any other colour.

THE ROLE OF PALM OIL IN CASSAVA-BASED RATIONS

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Palm oil retards the decomposition of the intermediate products of linamarin (acetone cyanohydrin) and amygdalin (mandelonitrile); thus, in animals fed cassava-based diets supplemented with palm oil, the delay in decomposition may prevent absorption of the linamarin. A basic medium (pH 8–9) accelerates the breakdown of these compounds.

L'huile de palme retarde la décomposition des produits intermédiaires de la linamarine (hétéroside cyanogénétique) et d'amygdaline (acide mandélique); par conséquent, en ajoutant de l'huile de palme à une ration animale à base de manioc, on retarde la décomposition de la linamarine et partant, on peut en prévenir l'absorption. Un agent de base tel le pH 889 accélère la dissolution de ces composés.

Cassava is a cheap, digestible source of calories for humans and domestic animals. However, feeding cassava flour to animals for a considerable time depresses their voluntary feed intake and rate of growth (Oyenuga 1961; Enriquez and Ross 1969; Pido and Adeyanju 1978). Some of the reasons postulated for this reaction include the presence of the cyanogenic glucosides linamarin and lotaustralin, which release hydrogen cyanide or hydrocyanic acid, a deadly poison, upon hydrolysis. The detoxification of hydrocyanic acid by the enzyme rhodanase releases thiocyanate, a goitrogen (Oke 1978). Other nutritional problems such as the complexing of lysine by aldehydes of cassava carbohydrates, especially when heated, and the low protein, vitamin, and mineral contents of cassava flour also limit the utilization of this feed source by domestic animals (Oke 1978; Hutagalung 1977). Several methods are used to process cassava roots to decrease the level of toxic compounds in the flour. Grinding, frying, fermenting, boiling, sun drying, and soaking are some of the methods in use. However, not all the toxic compounds are removed from the flour. Carmody (1900) observed that successive water extractions remove further quantities of hydrocyanic acid from cassava roots. Joachim and Panditteseker (1944) found that the amount of hydrocyanic acid released autolytically increased very rapidly as the amount of time allowed for autolysis was increased up to 24 h. Even when autolysis was essentially complete, a further quantity of hydrocyanic acid could be released by acid hydrolysis. Cooke and Maduagwu (1978) showed that free cyanide was rapidly removed from cassava chips but bound cyanide was less readily removed. These workers established that only a third of the bound cyanide is removed by autolysis at 46.5°C. Hill (1977) showed that 50 mg of linamarin given by stomach tube to rats killed them within 4 h and produced abnormal electrocardiogram tracings similar to those found in cyanide poisoning.

Hawksworth, Drasar, and Hill (1971) observed that *Escherichia coli* produce β-glucuronidases and β-galactosidases; enterococci produce β-glucosidases and β-galactosidases, and nonsporing anaerobes produce small amounts of all these enzymes except β-glucuronidases. These enzymes could hydrolyze linamarin, lotaustralin, and glucuronides.

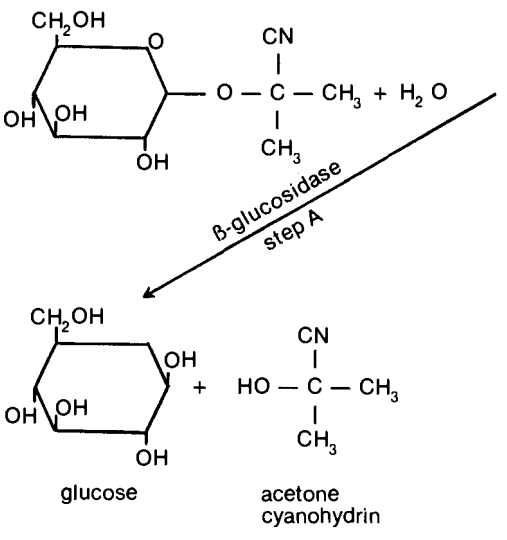
Sulfur and fats enable better utilization of cassava flour by animals. Fats, especially, have been noted to influence feed intake regardless of the density of the feed (Carew et al.1963). Hutagalung and Chang (1977) showed that pigs utilized cassava-based diets more efficiently when supplemented with 5–10% palm oil than did controls or pigs fed diets supplemented with lard or tallow. These researchers also stated that palm oil was more digestible than fats of animal origin. Hew (1975) stated that an 8% palm-oil supplementation of a cassava diet enabled faster growth by animals and beyond this level a plateau was reached. Other workers in this field have observed gains in weight when fats as well as methionine (0.2%) are added to cassava diets (Ross and Enriquez 1967; Hew and Hutagalung 1972; Maner 1974). Devendra and Hew (1977) fed pigs up to 30% palm oil in

10–24% cassava rations and observed no effect. In view of this, work at the University of Ife was designed to investigate the role of palm oil in cassava-based rations.

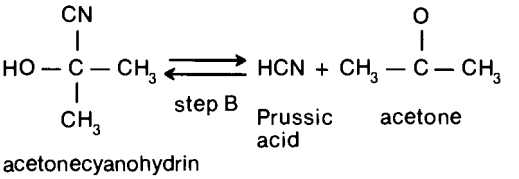
The intermediate products of linamarin and amygdalin (cyanohydrin and mandelonitrile, respectively) were synthesized according to the method of Vogel (1978). Decomposition rates of 0.2 μl aliquots in phosphate buffer (0.05 M) at different pH levels were investigated. The experiment was repeated with palm oil as the medium. The rate of hydrolysis of mandelonitrile was reduced markedly in the palm oil compared with that in aqueous media; the rate of hydrolysis of acetone cyanohydrin was variable. We measured the rate of hydrolysis as liberated hydrogen cyanide at 30°C using a modified recovery method by Gilchrist (1967).

With this approach, we attempted to discover whether palm oil has any effect on the breakdowns shown in the equations:

(1)

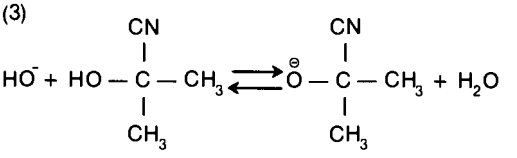


(2)

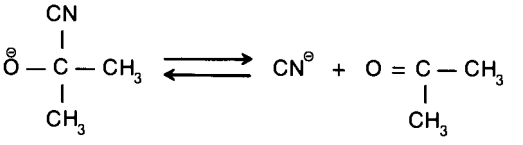


Our preliminary results showed that palm oil does slow down the decomposition of acetone cyanohydrin, which is expected, as cyanohydrins decompose in basic media; for example,

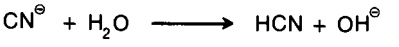
(3)



(4)



(5)



We are now working to evaluate the effects of palm oil on the decomposition of linamarin. One possibility is that, during digestion, palm oil prevents absorption and effects subsequent excretion of linamarin; however, Hill (1967) found no linamarin in feces of rats fed linamarin by stomach tube. He suggested that linamarin was either absorbed intact and excreted in the urine or changed to a yet unidentified metabolite and then excreted in the feces. Another possibility is that palm oil or a component of palm oil modifies the enzyme systems that hydrolyze and metabolize linamarin, most probably via glucuronides.

COMPARISON OF PRESSED AND UNPRESSED CASSAVA PULP FOR GARI MAKING

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We studied pressed and unpressed (dewatered and undewatered) fermenting pulp of 1-year-old cassava (variety Otupam) to compare their microflora and cyanide content. Although the microbial types isolated were the same, the populations of individual microflora were higher in the pressed (dewatered) pulp than in the unpressed. All the microorganisms grew well in both aerobic and anaerobic conditions. Hydrogen cyanide occurred more in the unpressed pulp, and some of the cyanide in pressed pulp was probably removed along with the expressed juice. Much of the remaining cyanide was probably released on hydrolysis by the endogenous enzyme linamarase during the fermentation of the pulp. Dewatering seems to be an effective way to reduce HCN levels in the pulp. It also seems to encourage the growth of microorganisms in larger numbers.

Analyse de la pulpe en fermentation, humide ou sèche, comprimée et non comprimée, de racines de manioc âgées d'un an de la variété Otupam afin de comparer la microflore et la teneur en cyanure. Les types microbiens sont semblables dans chaque cas mais la microflore est plus populeuse dans la pulpe comprimée (sèche) que dans l'autre. Tous les microorganismes se sont multipliés aussi bien en aérobiose qu'en anaérobiose. La pulpe non comprimée contenait davantage de cyanure d'hydrogène, que la pulpe non comprimée où une partie du cyanure a probablement été entraînée dans le liquide lors de l'opération; et presque tout le restant soumis à l'hydrolyse, libéré au cours de la fermentation par la linamarase, enzyme endogène. L'extraction de l'eau semble être un moyen efficace de réduire le taux de HCN contenu dans la pulpe. Cette opération favorise également la multiplication des microorganismes.

Cassava root, when processed, is an important food for some 200–300 million people in Africa, Asia, the West Indies, and South America. For these people it forms a major source of calories (Coursey 1973; Miller et al. 1975; Cooke 1978; Cooke et al. 1978). Cassava is a starch-producing root crop and ranks seventh among staple foods in the world (Montaldo 1977).

Despite its importance as a staple food, cassava can only be consumed after several processes (Coursey 1973) as it is cyanophoric, and the tissues release hydrocyanic acid when crushed or damaged. It contains the cyanogenic glucosides, linamarin and lotaustralin. It has been reported that the normal range of HCN content in fresh cassava root is 15–400 ppm (Khajarern et al. 1977). Variations of HCN levels are often due to the compound's volatility and highly reactive nature (Bissett et al. 1969).

The prolonged incorporation of improperly processed cassava products in diets leads to a high incidence of goitre, tropical ataxic neuropathy, cretinism, and deficiencies in sulfur, amino acids, and vitamin B_{12} among consumers (Nartey 1978). Several traditional methods are used to process the roots into a relatively safe food and to improve their palatability.

Collard and Levi (1959) using cassava pulp that was fermenting for gari isolated *Corynebacterium* sp., which was stated to split starch eventually to sugar. They added that the process created a favourable environment for the growth of the mould *Geotrichum candidum*.

They also attributed what they described as the spontaneous breakdown of cyanogenic glucoside to the acidity produced by the activity of *Corynebacterium* sp., thereby giving rise to the so-called two-stage fermentation of gari pulp. Their findings have been questioned by Okafor who in 1977 isolated *Leuconostoc*, *Alcaligenes*, *Lactobacillus*, and *Candida* spp. in fermenting pulp. The growth of lactic acid bacteria was not reported by Collard and Levi because, according to Okafor (1977), they used nutrient agar only as their medium, whereas he used a glucose yeast extract medium.

He argued that the presence of some free sugar in the cassava root, as reported by Ketiku and Oyenuga (1970), induced abundant lactic acid bacteria that utilize it. It is thought that differences in the findings of Collard and Levi were due to the

unpressed nature of the pulp with which they worked as well as to the variety and source of their cassava materials.

Our work was undertaken in an attempt to make a comparative investigation of the microflora involved in the fermentation of pressed and unpressed cassava pulp used in gari. The change in the cyanide levels of the pulp with increase in the period of fermentation was also studied.

MATERIALS AND METHODS

Fresh roots of 1-year-old cassava, Otupam variety, were washed and peeled. The cylinder left after the peeling was rewashed and grated with a hand grater; 5 kg of the pulp was put in a white, sterile cloth bag. Then an 8-kg weight was placed on a sterile glass sheet, and both were placed on the bag. Another 5 kg of cassava pulp was placed in a large glass beaker.

We used the method of Miles and Misra as described by Collins and Lyne (1976) to determine the population of microbes in the pulp. Subsequently, serial 10-fold dilutions of the pulp suspension were made; we used a pasteur pipette to introduce 0.025 ml of the dilutions onto eight previously dried plates of glucose yeast extract agar (GYA) (Okafor 1966a). The plates were left undisturbed and allowed to dry. One-half of the plates were incubated aerobically at 28°C, and the rest were placed in an anaerobic atmosphere of hydrogen in a closed jar also at 28°C. The plates were examined at 24-h intervals up to 120 h.

The colour, size, shape, texture, surface, elevation, and margin of the colonies developing on the plates were described, and the number of the various morphological types was recorded. Based on their gross morphology, the colonies were grouped into A, B, C, D, or E. The isolates were purified and stored at 4°C on labeled GYA.

Other characterization tests were carried out as outlined in Cowan and Steel (1970), Collins and Lyne (1976), and Skerman (1967). The cultures were then identified from Bergey's Manual of Determinative Bacteriology (1974).

The fungal colonies were purified on GYA, transferred to cornmeal agar, and examined after 48 h of growth at 28°C. They were identified from Larone's Guide to Identification (1976).

The method of Burns et al. (1970) was used in the determination of cyanide content of the pulp.

We homogenized 500 g of fresh, frozen cassava peel with 1000 ml of 0.1 M acetate buffer at 2°C using a Waring blender. The homogenate was filtered with a vacuum pump through Kieselgurgh into a flask surrounded with ice blocks. The filtered material was centrifuged at 500 rpm for 30 minutes at 20°C. The supernatant was stored in a deep freezer at 2°C as crude enzyme, and the sediment discarded.

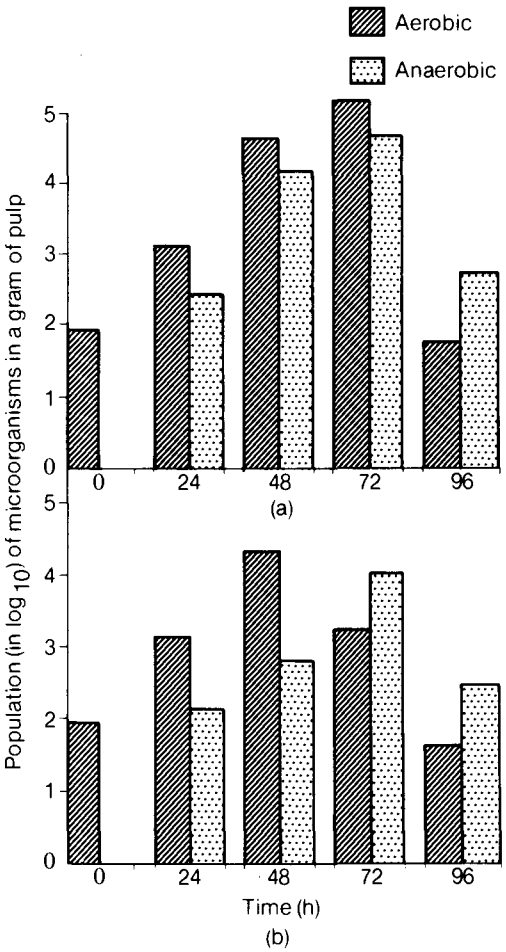

Fig. 1. *Aerobic and anaerobic growth of* Leuconostoc *sp. in pressed (a) and unpressed (b) fermenting cassava pulp.*

We placed 10 g of the fresh pulp in a 500-ml Kjeldahl flask and added 100 ml of distilled water; 10 ml of crude enzyme was added and the mixture shaken thoroughly and allowed to incubate for 1 h. Distillation was into a 300-ml volumetric flask containing 50 ml of 2% potassium hydroxide. Distillation was allowed to proceed slowly with the ends of the condensing tubes submerged in KOH; 200 ml of the distillate was collected in a 300-ml volumetric flask.

Then, 10 ml of 0.03 N alkaline picric acid solution was pipetted into 50-ml volumetric flasks containing 20 ml of distillate. The flasks were

placed immediately in a thermostat-controlled water bath to incubate for 5 min at about 94°C. The flasks were then cooled to room temperature and the optical density of colour was recorded from the spectrophotometer set at 540 nm.

We determined HCN concentration using the procedure of Burns et al. (1970). We mixed 10 g of pulp with 10 ml of distilled water (pH 7.0) and recorded the pH of the pulp, using a 290 MK2 meter. Pulp was oven dried to a constant weight at 105°C for dry-weight determination.

RESULTS

The microflora isolated were categorized as A,B,C,D, and E. The properties of the bacteria (A,B,C) identified them as *Leuconostoc*, *Lactobacillus*, and *Bacillus* spp. The fungi were described and were identified as *Candida* sp. and *Geotrichum* sp. The *Candida* specifically produced characteristic elongated blastospores on pseudohyphae on growth in cornmeal agar, whereas *Geotrichum* sp. produced many rectangular arthrospores of various sizes and roundness of ends.

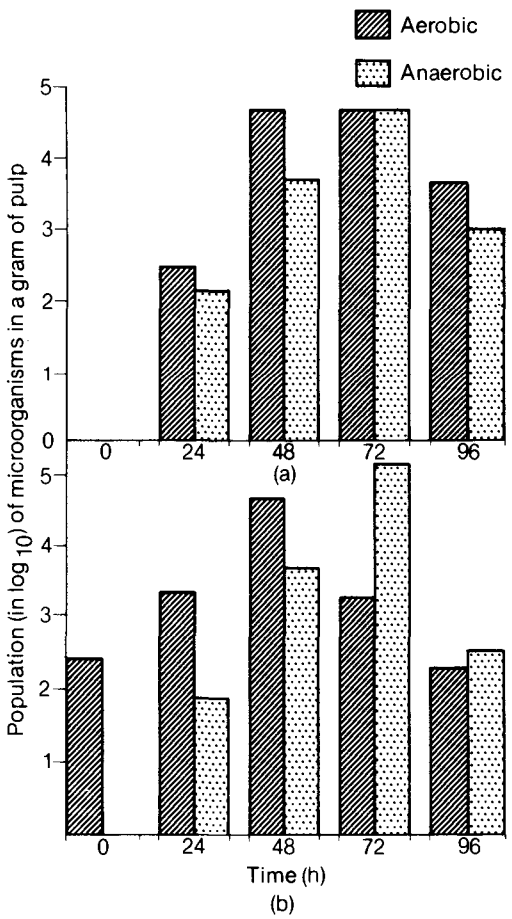

Fig. 2. *Aerobic and anaerobic growth of* Lactobacillus *sp. in pressed (a) and unpressed (b) fermenting cassava pulp.*

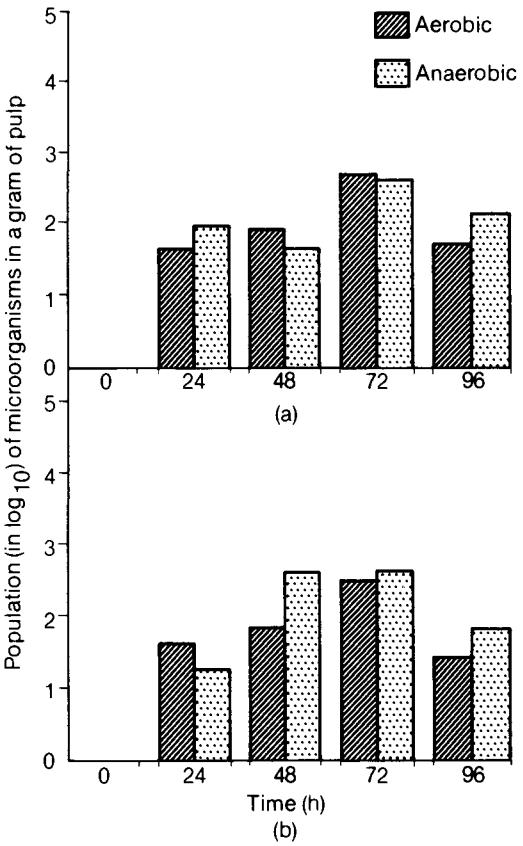

Fig. 3. *Aerobic and anaerobic growth of* Bacillus *sp. in pressed (a) and unpressed (b) fermenting cassava pulp.*

The same microorganisms were isolated from the pressed and unpressed fermenting pulp under aerobic and anaerobic conditions (Fig. 1–4). *Leuconostoc* sp. occurred almost immediately after the experiment was started and increased in numbers up to 72 h. Thereafter, growth declined. No growth was observed after 96 h. The highest population of this organism was recorded between 48 and 72 h when the pH fell from 4.8 to 3.8 in pressed and 5.6 to 4.3 in unpressed pulp. Pressed pulp supported the growth of larger numbers of this organism (Fig. 1).

Lactobacillus sp. was isolated in large numbers

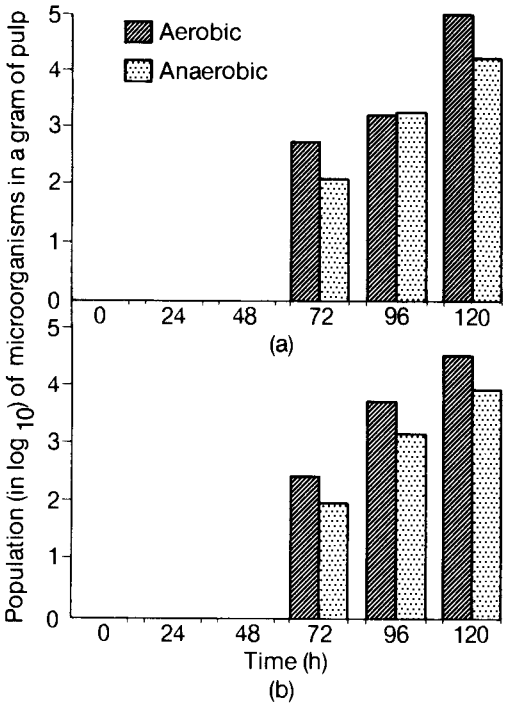

Fig. 4. *Aerobic and anaerobic growth of* Candida *sp. in pressed (a) and unpressed (b) fermenting cassava pulp.*

from both pressed and unpressed fermenting pulp under aerobic and anaerobic conditions. Growth started at the beginning of the experiment (Fig. 2), with the highest population occurring between 48 and 72 h when the pH fell from 4.8 to 3.8 and from 5.6 to 4.3 in pressed and unpressed pulp, respectively. In neither condition did growth take place after 96 h.

Bacillus sp. was isolated in both pressed and unpressed pulp after 24 h. Its members were fewer than the other organisms. Growth was recorded in both aerobic and anaerobic states (Fig. 3).

The yeast, *Candida* sp., was observed from 72 h and the numbers increased rapidly until the end of the experiment. The pH of the pulp was between 3.8 and 3.4 in pressed pulp and between 4.3 and 3.8 in unpressed pulp. The highest population was recorded after 120 h in pressed pulp. Higher numbers of organisms were recorded under aerobic conditions (Fig. 4).

Geotrichum sp. was observed in large numbers from 72 h. Both pressed and unpressed pulp supported rich growth of this organism under aerobic and anaerobic conditions. The highest population was recorded at 120 h in pressed pulp when the pH was 3.4 (Fig. 5).

The changes in cyanide content with increasing fermentation are shown in Table 1. The juice expressed from the pulp at 0 h contained 0.078 mg HCN/g. The cyanide content was higher in the unpressed pulp. The levels of cyanide content fell with increasing periods of fermentation.

The pH and moisture content of pressed pulp fell more rapidly than that of unpressed pulp. However, changes in pH and moisture content were less pronounced after 72 h of fermentation in both pressed and unpressed pulp.

DISCUSSION

Although the microbes occurring in the pressed and unpressed fermenting cassava pulp were the same, there were differences in number. Okafor (1977) has reported isolation of *Bacillus* sp. in some of his experiments in which a hand grater such as was used in our work was used. It would appear that organisms isolated would depend on how the cassava is grated.

The absence of *Corynebacterium* sp., which was readily isolated by Collard and Levi (1959) but which was insignificant in Okafor's experiment

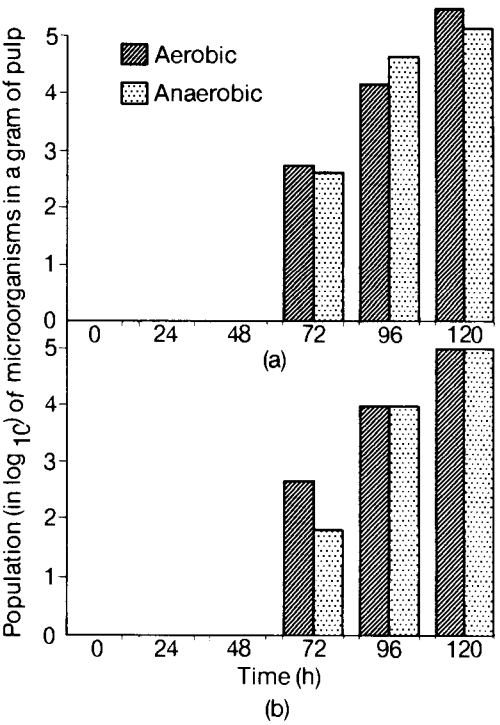

Fig. 5. *Aerobic and anaerobic growth of* Geotrichum *sp. in pressed (a) and unpressed (b) fermenting cassava pulp.*

Table 1. HCN content of pressed and unpressed cassava pulp (mg/g) calculated from mean of five samples.

Hour	Pressed pulp	Unpressed pulp
0	–	0.144
24	0.075	0.088
48	0.070	0.082
72	0.063	0.078
96	0.053	0.072
120	0.046	0.059

(1977), is noteworthy. The reason could not be that Collard and Levi did not dewater their pulp because no *Corynebacterium* sp. were found in our unpressed pulp either. However, they obtained their materials at Oshodi, whereas the university farm was the source of the cassava used by Okafor (1977) and for our experiment. It is, therefore, possible that the difference is in the varieties used or the location of the experiments.

Collard and Levi (1959), Collard (1963), and Akinrele (1964) reported isolation of *Geotrichum candidum* apart from *Corynebacterium manihot* but did not report isolation of lactic acid bacteria, whose presence was reported by Okafor (1977) and in our experiment. Our finding of *Leuconostoc* sp. and *Lactobacillus* sp. in large numbers supports the findings of Okafor, who attributed the failure of Collard and Levi to isolate lactic acid bacteria to their use of nutrient agar as their only medium.

The presence of *Geotrichum* sp. and *Candida* sp. during the later stages of fermentation is probably due to reduced pH because most fungi are known to prefer an acidic environment. Equally possible is the release of sugar by the activities of *Bacillus* sp. *Geotrichum* is often referred to as a sugar fungus because it grows where large amounts of sugar are found (Spencer and Uden 1977).

The observed growth of *Leuconostoc*, *Lactobacillus*, *Bacillus*, *Candida*, and *Geotrichum* spp. in both aerobic and anaerobic conditions is probably due to their facultative nature. Okafor (1977) explained the abundance of lactic acid bacteria in his experiment as due to availability of free fermentable sugars in the cassava roots. It is probable that these abound in both pressed and unpressed pulp. It was observed that the ability of fungi to respire sugar diminished with decreasing oxygen levels (Beech 1969; Oura 1969), whereas fermentation of glucose increased. The unpressed pulp probably created a more anaerobic condition due to its higher moisture content. Thus the observed higher number of *Candida* and *Geotrichum* spp. in pressed pulp during the later stages of fermentation is probably due to lower moisture content and higher oxygen levels in the pulp.

Pressed pulp contained less HCN than did unpressed pulp. The value of 144.0 mg/kg was obtained in this experiment with fresh, unpressed pulp. Other workers have reported various ranges of cyanide in cassava pulp. Wood (1965) obtained 6–190 mg/kg; Greenstreet and Lambourne (1933) reported 30–370 mg/kg; Oyenuga and Amazigo (1957), 29–213 mg/kg; and Bolhuis (1952), 31–151 mg/kg for the variety Basioro. The amount probably depends on the variety, source, and age of the roots.

Our results show that, although pressed pulp contained less HCN than did unpressed pulp, some HCN was retained. Also there was a significant amount of cyanide in the liquor expressed from the pulp. It probably contributed to the lower values obtained. Although a view is held that certain microorganisms can grow in cyanide medium by degrading it to nontoxic products of CO_2, ammonia, nitrate, or nitrite (Arima and Oka 1975), the role of the microflora in cyanide detoxification is yet uncertain. The fact that such large numbers of organisms were found in the cyanide-containing pulp suggests that either the cyanide does not affect these organisms or that they can degrade it.

CONCLUSION

From our work, it can be reasonably stated that dewatering fermenting pulp in gari making results in reduced cyanide toxicity, higher protein content resulting from the higher populations of microflora, and improved flavour of the product from the higher fungal growth. It is recommended that dewatering be continued, although more work should be done to improve the process.

We wish to thank the Department of Microbiology, University of Nigeria, Nsukka, and the National Root Crops Research Institute, Umudike, for making it possible for this work to be done.

GARI YIELD FROM CASSAVA: IS IT A FUNCTION OF ROOT YIELD?

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Twelve cassava cultivars constituting 11 hybrids, namely TMX 30395, TMX 1325, TMX 1624, TMX 59/159/91, TMX 30568, TMX 750, TMX 6, TMX 90, TMX 20, TMX 30211 from IITA, and 60506 were harvested 1 year after being planted at the Teaching and Research Farm of the University of Nigeria, Nsukka. Marketable roots of each cultivar were labeled and 100 kg were weighed out from each cultivar and processed into gari in a semimechanized gari factory. The cultivars were grown without fertilizers as is the practice among most farmers. The results showed that the cultivar with the highest root yields was not necessarily the best for gari production. Observations on gari yield and quality in relation to root yields are discussed. Plant breeders and agronomists should consider quality and quantity of gari, rather than mere root yields, in selecting new cassava cultivars for farmers. The hybrids have a lot of promise if the gari yield can be determined by means of time-of-harvesting experiments in the various ecological zones.

Douze cultivars de manioc comprenant onze hybrides, notamment TMX 30395, TMX 1325, TMX 1624, TMX 59/159/91, TMX 30568, TMX 750, TMX 6, TMX 90, TMX 20, TMX 30211 de l'IITA et 60506 ont été récoltés un an après leur plantation à la ferme de recherche et de formation de l'Université du Nigeria, Nsukka. Ces cultivars avaient été produits sans engrais, selon les pratiques traditionnelles des fermiers. Après étiquetage des racines de chaque cultivar, 100 k de chaque variété ont été transformés en gari dans une meunerie semi-mécanisée. Le cultivar à rendement supérieur/ha n'a pas donné nécessairement la meilleure qualité de gari. Les observations sur le rapport entre le rendement d'un cultivar et la qualité du gari sont actuellement à l'étude. Les phytosélectionneurs et les agronomes qui cherchent de nouveaux cultivars de manioc pour les fermiers devraient s'attacher à rechercher la qualité et la quantité de gari plutôt que le nombre de tubercules. Les hybrides deviendraient très populaires s'il était possible de déterminer les éléments nutritifs du gari par des expériences sur le temps de récolte dans les diverses zones écologiques.

Gari is the staple of the people in southeastern Nigeria and most of the West African countries. Balakrishnan and Sundararaj (1967) indicated that between 12 and 12.5 months after planting was the best time to harvest cassava. However, in Nigeria scarcity of food may at times force farmers to harvest their cassava just 8 or 9 months after planting. Cassava deteriorates quickly after harvest, and storage methods have not been very effective in enabling farmers to store their roots for even 10 days after harvest.

Ibe (1979) described the characteristics of top-quality gari in terms of good binding quality, low HCN, low fibre content (not more than 3%), and low moisture content of not more than 8%.

Farmers evaluate their cassava roots in terms of gari production and starch content; they prefer to grow cassava cultivars that give high root yields as well as high starch and gari yields.

The objective of this paper is to evaluate the gari yield of some TMX cassava hybrids, the overall goal being to determine which cultivars can be processed for high quality and quantity gari. One of the ways of improving the farmers' lot is to provide them with high-yielding cultivars of crops through genetic manipulation. High yields should be reflected in improvements in the economic well-being of the farmers. Hahn (1978) indicated that the cassava ideotype should be short, with little branching to conform to mechanization, early maturing, and resistant to pests and diseases, and should contain enough starch. Some of the TMX cassava cultivars discussed in this paper are tending to conform to Hahn's description of cassava plant ideotype.

MATERIALS AND METHODS

Twelve cassava cultivars (TMX 30395, TMX 1325, TMX 1624, 631024, TMX 59/159/91, TMX 30568, TMX 750, TMX 6, TMX 90, TMX 20,

TMX 30211) and a control (60506) were grown without fertilizers in a randomized, complete block design with four replications. These were planted in September 1977 and harvested during the first week of October the following year. All the harvested, marketable roots were bulked according to cultivars. Thereafter, 100 kg of each cultivar were peeled by 10 gari producers who were engaged specifically to simulate village production.

After being peeled, the roots were washed and grated immediately. The grated roots or pulps were bagged and stacked in a dewatering device situated at the factory. Four days later the pulps were sieved according to cultivars and fried, the gari producers taking part in the frying of each cultivar. The fried gari was kept in a drying chambre overnight to cool and was weighed the next day for a determination of the gari yields.

RESULTS AND DISCUSSION

The figures obtained suggest that root yield per se is not necessarily a reliable indicator of the amount of gari that can be produced from the cultivars. Gari yield and quality varied sharply from root yields of the various cultivars.

631024 gave the highest root yield (21.5 t/ha) but not the highest amount of pulp for gari production. TMX 30568 gave the highest yield of gari in t/ha, but the gari was not high in quality. TMX 750 produced the smallest amount (0.9 t/ha) and the worst quality gari. The cultivar that produced the highest root yield, 631024, produced only 9%, or 1.9 t/ha, fried gari. However, 631024 ranked highest, followed by the control (60506) and TMX 1325 in terms of quality of gari.

TMX 30211 gave a root yield of 17.4 t/ha and a gari yield of 16%, or 2.7 t/ha; TMX 30568 gave 15.7 t/ha for roots and 20%, or 3.1 t/ha, for gari. TMX 1325 produced 14.9 t/ha for roots and 16.8%, or 2.5 t/ha, for gari. TMX 90 yielded 14.8 t/ha for cassava roots and 3 t/ha for gari. For TMX 59/159/91 and TMX 20, the root yields were 14.1 and 14.0 t/ha, respectively. However, TMX 20 produced a gari yield of 11.9%, or 1.7 t/ha, compared with 6.7%, or 1.0 t/ha for TMX 59/159/91.

It is important to consider gari processing as one of the reliable means of assessing cassava hybrids. Farmers may easily avoid use of hybrid cultivars for producing specific foods if their first attempt is a disappointment.

Most of the cultivars in our study grew very vigorously without fertilizers; however, the yields were generally low because the cultivars were grown on marginal lands.

YAMS

PARAMETERS FOR SELECTING PARENTS FOR YAM HYBRIDIZATION

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White yam, *Dioscorea rotundata*, produces viable seeds and can, thus, be improved by hybridization. Results of studies on certain desirable attributes of parent cultivars are presented and discussed. Yam production and improvement will advance fastest when true seeds can be easily grown in farmers' fields. It is recommended that research shift toward finding nicking parents for yam production via true seeds.

Dioscorea rotundata, espèce d'igname blanche, donne des graines viables, ce qui la rend propre à l'amélioration par hybridation. Cette étude présente et discute les résultats des recherches sur divers caractères souhaitables chez les cultivars parents putatifs. On reconnaît que l'amélioration et la production d'ignames progresseront plus rapidement lorsque les semences pourront être produites chez le fermier même. Il est donc recommandé de diriger les recherches sur la mise au point de parents d'élite pour la production d'ignames par semences.

Most yams are grown in the humid tropics, especially in Africa, Southeast Asia, India, and the Caribbean islands. Nigeria's yearly production is estimated at 1.5 Mt, about 75% of West Africa's production of the crop. *Dioscorea rotundata* (white yam) is the preferred species in many parts of West Africa, although a few other edible species are planted. White yam is believed to be indigenous in the area stretching from Ivory Coast through Ghana, Togo, Benin Republic, Nigeria, and Cameroon.

Yam improvement over the years has been by selection of "good" tubers by farmers planting new crops. As a result, "good adapted" cultivars have been selected for the different yam cultivation niches. Martin et al. (1975), based on their findings, suggested "poor distribution of the better varieties and the consequent use of inferior types in many regions that would not be used if better varieties were known." However, they recognized that yield reductions might be caused by viruses and diseases if interregional introduction of cultivars were adopted. Although flowering and seed set had been recognized in some species of yam, breeding by hybridization, especially in *D. rotundata* was hampered by poor seed set, low seed viability, and the small size of tubers produced from true seeds (Waitt 1961). The work of Sadik and Okereke (1975b) and Okoli (1975) in germinating true seeds of *D. rotundata* has renewed interest in the possibilities of improving yams by hybridization.

This paper reports some of the work that had to be done so that meaningful hybridization schemes could be evolved.

IMPROVEMENT OBJECTIVES

Summarizing yam breeding objectives, Wilson (1978) indicated the need to breed cultivars "which have all the conventional attributes of high yield, disease and pest resistance, storability and culinary quality. In addition, they must possess characters which lower the labour requirements, eliminate staking and reduce the amount of planting material required."

Planting yams by means of true seeds is a producer's dream and should become an important breeding objective. Thus, producing parents whose seeds will, in the first year after being planted, yield good-sized and well-shaped tubers will mark the end of efforts to begin constructing ideal parents for yam improvement.

IMPORTANT CHARACTERISTICS FOR PARENTS

LOW SEED TO YIELD RATIO

The cost of seed yams, estimated at one-third the total outlay of yam production (Nwosu 1975), has been identified as a major constraint to increased yam production. Okoli (unpublished) assessed the input : output relationships in different cultivars of yam species for a 3-year period (Table 1).

Table 1. Average "seed" : yield ratio of yam cultivars planted at Umudike for "seed" and for sale as food.

Cultivar	"Seed" yam production			Food yam production		
	Planted (kg/ha)	Harvested (kg/ha)	Ratio	Planted (kg/ha)	Harvested (kg/ha)	Ratio
D. rotundata,						
Nwapoko	2.8	14.2	5.07	4.7	16.5	3.51
Ekpe	1.7	6.0	3.53	1.5	6.2	4.13
Abi	1.7	6.7	3.94	2.9	8.5	2.93
Obiaoturugo	2.2	6.2	2.82	3.6	12.3	3.42
Okwocha	2.1	6.5	3.1	2.2	10.0	4.55
D. cayenensis, Oku	1.8	6.1	3.39	4.5	10.8	2.40
D. alata,						
UM 680	1.9	9.2	4.84	2.3	15.4	5.70
Ominaelu	–	–	–	2.0	13.5	6.75
D. dumetorum, Ona	–	–	–	8.9	13.4	1.51

Many workers have reported on the relationships between "seed" planted and the harvest yield. Although it is known that larger seed pieces (and hence larger seed input per hectare) sprout more readily, produce more vigorous plants, and yield more per plant than do smaller pieces, the desirable size for seed pieces remains controversial.

The observed relationship between the total weight planted and that harvested in the various varieties of yam has significance in yam hybridization programs. Varieties having more favourable input : output ratios are more attractive for use as parents in hybridization programs than are those having larger ratios even when yields of the different varieties are the same.

Minimum or No Staking Requirements

Staking is another major cost item in yam production. Although in the Guinea savanna regions of Nigeria, yams are not usually staked, farmers know that such yams as find support invariably yield better than those crawling on the mounds. In studies on the effect of staking height on the yield of yams, it was found that the height of stakes beyond 2 m does not significantly increase yield of yams (Okigbo 1973). Apart from being expensive, tall stakes obstruct farm machinery used for weeding or harvesting the yams. In a 2-year study to evaluate the yields of eight yam cultivars from three species, it was shown that in some cultivars, staking makes only marginal differences to overall yield. Thus, although yields of two varieties of yams may be similar when staked, the variety with the smaller difference between unstaked and staked yields is preferable as a parent in a hybridization program (Table 2).

Efficient Dry-Matter Distribution to Tubers

Yam stores most of its photosynthates in underground parts called tubers. The proportion of total photosynthates stored in the tubers as against those found in inedible parts varies among species and among varieties of the same species. In a study of

Table 2. Unstaked : staked yield ratios in yam cultivars at Umudike.

	1978	1979
D. rotundata,		
Nwapoko	1:1.193	1:1.219
Obiaoturugo	1:1.159	1:1.147
Ekpe	1:1.021	1:1.255
Okwocha	1:1.479	1:1.20
Abi	1:1.143	1:1.281
D. alata,		
Ominaelu	1:1.174	1:1.716
UM 680	1:1.384	1.049:1.0
D. dumetorum, Ona	1:1.0	1:1.095

the rate of dry matter accumulation and partition in four yam varieties from two species, Okoli (1980) found an inverse relationship between total yield and the proportion of total dry matter allocated to the tubers. That is, low-yielding cultivars allocated a higher proportion of the dry matter produced to the tuber than did higher-yielding cultivars. Thus, in a hybridization scheme, using physiologic (partition) efficiency as an index for selection of parents might lead to faster progress in yield improvement than using such complex indices as yield.

Adaptation to Environment

Yam cultivars are known to be particularly selective of their growth ecology — soils, rainfall regimens, daylength, etc. *D. rotundata* cv. Ekpe is an early maturing yam commonly planted in the alluvial soils of the Anambra flood plains of Southeast Nigeria. Yields under local cultural practices reach 15–20 t/ha. In the sandy loam soils of Umudike, however, the Ekpe cultivar hardly yields up to 5 t/ha, although it remains early maturing.

In yield trials of eight cultivars from two yam species over a 3-year period at Umudike, Okoli (unpublished) showed that the two highest-yielding cultivars of *D. rotundata* — Nwapoko and Obiaoturugo — and the Um 680 cultivar of *D. alata* can be recommended for this area. However, Nwapoko does not flower in this environment and, therefore, cannot be considered in the development of parents for seed-grown yams.

Consistent and Profuse Flowering

Yams are mostly dioceous, although some cultivars do not ordinarily flower, and others have both staminate (male) and pistillate (female) flowers on the same plant. There is, however, a preponderance of staminate inflorescence (141 males and 106 females) in the germ plasm collection at the National Root Crops Research Institute (NRCRI) in Nigeria, which includes 900 accessions. In selected farmers' fields near Umudike, the ratio is approximately 4 staminate : 1 pistillate : 2 nonflowering cultivars.

It appears that the size of sett planted affects flowering in pistillate plants but only the profuseness of flowering in staminate plants. In the planting of yams desired for hybridization, therefore, large tubers rather than small setts should be used. Also, because of differences in the periods of floral initiation (staminate plants usually flower earlier), staminate plants should be planted at weekly intervals for 4 weeks so that pollen is available when pistillate inflorescences are receptive.

Absence of Browning in Tuber Flesh

A criterion for selection of progenies used at late stages of yam breeding at NRCRI is the absence of browning of the tuber when cut and exposed to air. Browning results from oxidation of phenolic compounds present in the yam tuber.

The majority of tubers derived from seed have this browning tendency, which is rarely seen in cultivars being grown by farmers. Flesh colour of the cut and exposed tubers is scored 1 through 5, where 1 is dark brown and 5 is white. Clones scoring less than 3 are rejected.

Viability of Seeds

Yams available for food will be increased by up to 30% when true seeds rather than tubers or tuber pieces are used by farmers planting new crops. The ultimate breeding objective, therefore, is to produce such pistillate and staminate cultivars that will nick and produce many viable seeds and whose seedlings will yield well-shaped, uniform, medium-sized tubers. That done, breeding for pest and disease resistance, long shelf-life, good culinary qualities, etc. become attractive objectives. Obtaining other qualities without the means of transferring them by hybridization is almost valueless, as the good qualities cannot be multiplied quickly for distribution to farmers. Consequently, progenies that do not flower are rejected in the breeding program.

Conclusion

The varieties selected for use as parents in a yam hybridization program should reflect the breeding objectives. It is important to identify the attributes of ideal parents and to understand their behaviour in the anticipated growth environments and under the expected cultural management systems. If seed culture is to be adopted in at least some stage of yam production, flowering with profuse and viable seed production must be given a prominent place in yam improvement programs.

ANTHRACNOSE OF WATER YAM IN NIGERIA

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Field symptoms of anthracnose of water yam (*Dioscorea alata*) in Nigeria are described. Isolation studies revealed that more than seven organisms, namely: *Colletotrichum* sp.; *Botryodiplodia theobromae; Fusarium* sp.; *Pestalotiopsis* sp.; *Syncephalastrum racemosum; Scopulariopsis fusca*; and *Curvularia* sp. are involved in the disease syndrome. *Colletotrichum* sp. is described. The conidia measure 15−30 × 3−5 μm and enter the host through stomata and by direct cuticular penetration. Inoculation studies showed that *Colletotrichum* sp., which was commonly isolated, could not produce serious infection in the absence of a second pathogen. *Colletotrichum* inoculated alone produced lesions measuring between 0.1 and 4 mm with few lesions per leaf, whereas *Colletotrichum* inoculated in combination with either *Botryodiplodia* or with both *Botryodiplodia* and *Fusarium* produced lesions measuring up to 20 mm, with many lesions per leaf. Infection was more serious on the lower than on the upper leaf surface, probably because of the absence of stomatal apertures on the upper leaf surfaces of *D. alata*. Greenhouse tests confirmed that tuber-borne, soil-borne, and infected yam debris (vine, petiole, and leaf) inocula of the pathogens were important in the development of the anthracnose disease of water yam. Therefore, control of tuber-borne inoculum, disposal of infected debris, and careful handling of harvested tubers are an essential part of an integrated program for control of the anthracnose disease of *D.alata*.

Description des symptômes d'anthracnose, chez l'igname d'eau *Dioscorea alata L.* observés sur le terrain au Nigeria. Des études spécifiques ont révélé que le syndrome de la maladie intéressait plus de sept organismes, notamment: *Colletotrichum* sp., *Botryodiplodia theobromae* Pat., *Fusarium* sp., *Pestalotiopsis* sp., *Syncephalastrum racemosum* Cohn ex Schroet, *Scopulariopsis fusca* Zach; et *Curvularia* sp. La conudie mesure 15 − 30 × 3 − 5 μm. et elle s'introduit dans l'hôte par les stomates ou la cuticule. Des études par inoculation ont démontré que *Colletotrichum* sp., facile à isoler, ne pouvait provoquer d'infection grave en l'absence d'un deuxième pathogène. L'inoculation de *Colletotrichum* seule a provoqué des lésions mesurant entre 0,1 et 4 mm, en petit nombre sur une même feuille, alors que l'inoculation de *Colletotrichum* associée à *Botryodiplodia* ou à la fois *Botryodiplodia* et *Fusarium* faisait apparaître des lésions mesurant jusqu'à 20 mm et assez nombreuses sur une même feuille. L'infection était plus marquée sur la face inférieure de la feuille que sur la face supérieure, probablement à cause de l'absence de stomates sur la surface supérieure des feuilles de *D. alata*. Des essais réalisés en serre ont confirmé que les pathogènes contenus dans le tubercule, le sol où des débris d'ignames infestées (tige, pétiole et feuille) jouent un rôle important dans le développement de l'anthracnose chez les ignames d'eau. Par conséquent, le programme intégré de contrôle de *Dioscorea alata* doit nécessairement comprendre la surveillance des tubercules vecteurs, l'élimination des débris infestés et un soin particulier apporté à la manutention des tubercules récoltés.

Yam dieback, generally called anthracnose, is a major disease of *Dioscorea alata* (water yam) in the South Pacific (Fa' Anunn 1977), the Caribbean (Ferguson 1974), Guyana (Fournet et al., 1975), Asia (Prasad and Singh 1960), New Zealand (Jackson and Newhoot 1978), and Nigeria (Waitt 1963; Coursey 1967b; IITA 1974, 1975; Nwankiti and Arene 1978).

The disease in the Solomon islands has been described by Jackson and Newhoot (1978) as two different diseases, one caused by *Colletotrichum gloeosporioides* (the perfect stage), *Glomerella cingulata*, which causes typical anthracnose lesions on leaves of some stands, and one caused by *Rhizoctonia solani*, which causes blackening of leaves and stems. Jackson and Newhoot (1978) pointed out that the two diseases could combine, with the result that lesions of *C. gloeosporioides* become superimposed on leaves and stems already affected by epidermal blackening induced by *R. solani* root infection.

Ordinarily, symptoms such as anthracnose lesions and epidermal blackening have been taken as the basis of distinction of anthracnose from the

blotchy or generalized blackening of upper, exposed surfaces, supposedly caused by *R. solani*. The organisms isolated most commonly are *Colletotrichum* sp., *Botryodiplodia* sp., and *Fusarium* sp. *B. theobromae* has been regularly implicated as one of the organisms causing rot of tuber crops in Nigeria (Ogundana et al. 1970; Okafor 1966a), especially on *Dioscorea* sp. *Fusarium* sp., especially *F. solani*, has been associated with *B. theobromae* as rot-causing organisms whereas *F. equiseti* has been described as leaf saprophyte of *D. rotundata* (Nwankiti 1978). The isolation of *Colletotrichum* sp., *Botryodiplodia* sp., and *Fusarium* sp. on diseased leaves of *D. alata* (IITA 1974, 1975; Jackson and Newhoot 1978) and the fact that these organisms are closely related to *Tubercolariaceous hyphomycetes* (Bassey 1950) make it necessary to find out how these organisms interact, relative to disease expression. Thus, the field description of the disease, isolation of possible organisms involved in the disease, the potential pathogenicity of each isolate alone and in combinations, and the transmission of the causal agents are especially noteworthy.

MATERIALS AND METHODS

FIELD LAYOUT

An experiment on the symptoms of anthracnose was laid out on a randomized complete block design in six replicates. We used Obunaenyi cultivar as the test crop. Two other cultivars, Um 680 and Ominaelu, were planted separately.

ISOLATION EXPERIMENTS

Colletotrichum sp. grows readily on common artificial media (Ou and Walker 1945). We obtained cultures by placing fragments of diseased tissues in 2% Chlorox (sodium hypochlorite) for 1 minute, rinsing in distilled water, and plating on four media — namely, potato dextrose agar, Czapek dox agar, cornmeal agar, and Martin's medium (Okpala 1975) composed of agar 23 g, magnesium sulfate hydrated 0.5 g, dextrose 10 g, potassium dihydrogen phosphate 1 g, peptone 5 g, water 11 litres, and 1% Rose Bengol 2 ml. Beginning early in the planting season, around May, we isolated organisms from the plant parts (leaves, petioles, and vines) with lesions of different sizes and colour (brown through dark brown to black). Four hundred or more lesions of different sizes and colours were collected from the experimental farm and were used within months of disease appearance in the field.

INOCULATION EXPERIMENTS

Colletotrichum sp. as isolated from naturally infected yam plants produced few or no spores on potato dextrose agar (PDA), but abundant spores were obtained in Czapek dox agar, and Martin's medium; 15–20-day-old cultures were used in inoculations unless otherwise stated.

Inoculations were made in the greenhouse usually on Obunaenyi, a very susceptible cultivar. Yam setts, each weighing 50 g, were sterilized in 40% Chlorox and were planted in plastic pots measuring 20 × 20 cm with autoclaved top soil weighing 1739 g. One yam sett was planted in each pot. For each inoculation experiment, pots with sprouts of the same stage of development were selected; we inoculated the plants 2 months after planting to avoid overgrowth of the stands.

Five pots, each containing one stand with at least 15–18 leaves, were used for each treatment, and only 10 leaves counting from the base were inoculated per stand. The treatments were inoculation of the upper surface of the leaf; inoculation of the lower surface of the leaf; inoculation followed by needle wound on the upper surface of the leaf; and inoculation followed by needle wound on the lower surface of the leaf. Spore suspensions of 5.3×10^6 spore/ml were applied by means of an atomizer. The moisture in the greenhouse was maintained by frequent watering of the wall wrapped with polythene sheets; the floor, littered with woodshavings was soaked continuously but free water was not allowed to accumulate on the plants. This kept the humidity between 97 and 100%. The temperature varied between 20 and 26°C. Readings were taken 4 weeks after inoculation, and the percentage of leaves infected for each treatment was recorded as a measure of susceptibility.

INTERACTION OF THE ISOLATES

In view of the fact that *Colletotrichum* sp. was always isolated along with *Botryodiplodia* sp. and at times with other organisms, the pathogenicity of the organisms and their interactions was studied in the greenhouse. *Colletotrichum* sp., *Botryodiplodia theobromae*, and *Fusarium* sp. were grown on 20 ml of Czapek dox agar and Martin's medium in 20 × 100 mm sterile glass petri dishes. Conidia of the organisms used for the inoculations were collected from 14–22-day-old cultures. Conidia of the *Colletotrichum* sp. were regarded as mature when an oily exudate was found at the tip of the acervuli. The acervuli were collected with forceps and crushed so that the spores were released; the same was done for *Botryodiplodia* sp., which also produced acervuli. Each isolate was suspended in

distilled water and filtered through sterile layers of cheesecloth to remove mycelial fragments. We adjusted each suspension to 4.7×10^5 spores/ml for individual pathogenicity tests using a hemocytometer. To prepare combinations of the conidia of the organisms, we mixed equal volumes of individual organism suspensions.

SPORE PENETRATION

Leaves to be examined for germination and penetration by *Colletotrichum* sp. were excised, placed in moist petri dishes, and incubated at room temperature (between 26 and 28°C). We observed spore germination, appressoria formation, and fungal penetration 2, 3, 6, 12, 24, 36, and 72 h after inoculation by peeling and fixing the epidermis in lactophenol in cotton blue.

TRANSMISSION STUDIES

Soil and tuber transmission of *Colletotrichum* sp. in water yam had not been demonstrated. More than 100 Obunaenyi yam setts were washed with distilled water and the washings filtered and plated in Martin's medium prepared as usual but with 30 ppm streptomycin sulfate $(C_{21}H_{39}N_7O_{12})_2 \cdot 3H_2SO_4$ to discourage bacterial growth.

Greenhouse experiments were conducted in 1980 at Umudike. Field soil infested with the disease in the previous year's planting was placed in 72 pots (30 × 25 cm). Thirty-six of the pots were autoclaved. Seventy-two tuber setts of the susceptible cultivar Obunaenyi, each weighing 80–100 g, were selected from field-grown tubers in 1979 and planted in each pot. Thirty-six of these setts were sterilized in 40% Chlorox for 0.5 h before being planted. Three pots were planted for each of the four treatments replicated six times. The four treatments were clean tuber setts (treated with 40% Chlorox), autoclaved soil; clean tuber setts, infested soil; infested tuber setts, autoclaved soil; and infested tuber setts, infested soil. Each plot was covered with clean polythene sheets to the height of 90 cm to prevent contamination and to maintain a high relative humidity around the stands. Incidence and severity were recorded at 30, 45, and 60 days.

Setts of the susceptible cultivar Obunaenyi, each weighing 25–40 g, were placed in 40% Chlorox for 0.5 h and planted in autoclaved soil in plastic pots 10 × 10 cm. Twenty-four of them were dipped in spore suspension of *Colletotrichum* sp. 4.2×10^6 spore/ml before being planted, and spores were inoculated on the soil in another 24 pots. The remaining 24 pots received distilled water. Treatments were replicated six times with each plot having four pots.

Diseased plant materials — vines, leaves, and petioles — kept in pots containing sterilized soil were exposed to different weather conditions prevailing in the field from August 1979 through April 1980; 60 plastic pots 10 × 10 cm were each filled with 400 g of autoclaved soil and planted with sterilized (treated with 40% Chlorox) yam setts, each weighing 20–30 g. There were three treatments each, replicated four times, with five pots per plot. The three treatments were infected yam vines and petioles; infected yam leaves alone; uninfected wood shavings (control). These were used as mulch on the planted pots. The pots were watered four times a week.

RESULTS

FIELD SYMPTOMS

In the field we found that the leaves, petioles, and vines of *D. alata* developed anthracnose. Appearance of small, round to irregular, brown spots on the leaves in late April and May synchronized with the initial rains. From these brown spots, we were often able to isolate *Colletotrichum* sp. These spots, which were mostly surrounded by yellow halo, coalesced, forming larger necrotic spots. The underside (lower surface) of the leaves was usually invaded first, especially those nearest the soil. Later, infection became more severe on stands not staked early. Both mature and young leaves were susceptible, but infection started from lower leaves and moved upward (Table 1). The percentage of leaves infected from ground level to 0.02 m was significantly ($P=0.01$) higher than at 0.2–0.4 and 0.4–0.6 m up the vine.

Dark brown to black spots on stems or vines spread and coalesced in most cases to shiny black. Infection of the petiole started as tiny brown to black spots at the base of the lamina and the point of attachment of the petiole and vine. These spots coalesced into shriveling and premature abscission

Table 1. Percentage of infected leaves at three heights above ground in yams at 80 days after planting (average of five stands).[a]

	0–0.2 m	0.2–0.4 m	0.4–0.6 m
	29	26.9	16.17
	15.7	4.9	0.0
	43.20	10.20	10.30
	19.70	5.0	6.50
	32.70	16.0	9.40
	26.70	12.10	9.10
Mean	27.83	12.52	8.67

[a]Standard error = 5.4998. LSD (0.01) = 10.06.

Table 2. Organisms isolated from different lesion sizes.

Cultivar	Diameter of lesion (mm)	Colour of lesion	Lesions examined	Organisms isolated	(%) of each
Obunaenyi	0.3–3	Brown with/ without yellow halo	100	*Colletotrichum*	80
				Botryodiplodia	20
	3–5	Brown with/ without yellow halo	100	*Colletotrichum*	40
				Botryodiplodia	60
	>5	Brown to black	100	*Botryodiplodia*	30
				Colletotrichum	15
				Fusarium	20
				Pestalotiopsis	5
				Syncephalastrum	5
				Scopulariopsis	5
				Curvularia	2
UM 680	0.3–5	Brown	50	*Colletotrichum*	14
				Fusarium	
Ominaelu	0.1–0.5	Brown	50	*Colletotrichum*	8

of the leaves. Infection of the vine started on the membranous wings of the stem and spread to the vine. In most cases, the upper part of the shoot grew away from the disease, leaving a few healthy leaves at the tip.

In some very severe cases, defoliation proceeded to the tip of the stand, resulting in complete death. When the plant died, new shoots developed from the base but many of these also died. This process continued till about August and completely eliminated tuber formation. Young stands were more susceptible when the humidity was very high.

The reaction of different cultivars to the disease differed slightly. Among the very tolerant cultivars, older leaves were affected, late in the season. In cultivar Um 680, the infection was restricted from advancing further, whereas in cultivar Ominaelu infection was at times restricted to pinhole spots with a discernible brown halo surrounding the affected areas, thus suggesting hypersensitivity.

Isolation Experiments

At the time of the first isolations, brown lesions measuring between 0.3 and 3 mm showed no acervuli (setae) when examined under the microscope, but 80% of the resulting colonies yielded *Colletotrichum* sp. alone (identified by the Commonwealth Mycological Institute, London), and 20% yielded *Botryodiplodia theobromae* (Table 2). In later isolation experiments, we used larger lesions (3.5 mm in diameter), and *Botryodiplodia* sp. was isolated more often than *Colletotrichum*, 60% yielding *Botryodiplodia*. In lesions larger than 5 mm in diameter, especially when the rains set in properly, *Botryodiplodia theobromae*, *Colletotrichum* sp., *Fusarium* sp., *Curvularia* sp., *Pestalotiopsis* sp., *Syncephalastrum racemosum*, and *Scopulariopsis fusca* were isolated. *Botryodiplodia theobromae* was more frequently isolated, and the percentage of *Colletotrichum* sp. colonies gradually decreased to 10%. However, more setae were observed on lesions, and more organisms were attracted to the lesions caused by *Colletotrichum* sp. Very few lesions on the resistant cultivars Um 680 and Ominaelu yielded *Fusarium* and *Colletotrichum*.

Thus, it became clear that these organisms, whether isolated or many, are commonly associated with *Colletotrichum* sp.

The fungus *Colletotrichum* grows well on Czapek dox agar and Martin's medium with profuse sporulation. Mycelium is septate, branching, hyaline when young, the walls becoming darker and thicker and the cytoplasm denser with age. By close intertwining of thick-walled hyphae, black stromata are formed. Acervuli are brownish in nature, but dark brown in culture, numerous, globose to saucer-shaped in culture media. They are formed on stomata beneath the cuticle by formation of a palisade layer of short hyaline conidiophores, which ruptures the cuticle. Scattered through the acervulus are numerous thick-walled, dark setae, which do not bear conidia.

Conidia are hyaline, nonseptate, rounded at the ends, some with prominent refractile globules at the two ends. Conidia are borne acrogenously, being budded at the tip of the conidiophores one at a time. They measure 15–30 × 3–5 μm.

Colletotrichum sp. can infect both intact leaf surfaces, but the lower leaf surfaces are more susceptible. In our studies, more infection was obtained when the leaves were wounded; 10% of unwounded leaves exhibited infection on their upper surface, whereas 62% showed infection on the lower surface. The figures for wounded leaves were 32% for upper surface and 66% for lower surface.

Interaction of the Isolates

Botryodiplodia theobromae and *Colletotrichum* sp. inoculated singly are potential pathogens of the host plant but *Fusarium* is not. A combination of either *Colletotrichum*, *Botryodiplodia*, and *Fusarium* or *Colletotrichum* and *Botryodiplodia* produces serious infection. The petioles and vines are even infected. Lesions are dark brown. In our studies, *Colletotrichum* and *Botryodiplodia* were reisolated wherever they were inoculated, but *Fusarium* was isolated in inoculated plants involving the three organisms only from advanced lesions. Tables 3 and 4 indicate also that the number of leaves and petioles affected and the number of lesions produced per leaf when *Colletotrichum*, *Botryodiplodia*, and *Fusarium* were inoculated together were higher than for any other treatment, but *Fusarium* did not seem to contribute.

Penetration by Colletotrichum

Spores of the *Colletotrichum* sp. on excised leaves of sprayed plants germinated within 3–5 h after inoculation. Spores produced two or three germ tubes that originated from both ends of the spore and from the side. Few appressoria were formed within 46 h. Germ tubes that did not produce appressoria continued to grow and branch profusely.

Infection of *D. alata* resulted from penetration of the epidermis via appressoria. Some hyphae were also observed to penetrate the stomata without appressoria formation. But most of the infection occurred through direct penetration by infection pegs formed from appressoria. Those hyphae without appressoria entered only through stomata.

Transmission Studies

We demonstrated that anthracnose could be both tuber-borne and soil-borne. Although the incidence in clean tubers, infested soil (20.73%) was not significantly different from the other two treatments — namely infested tuber, autoclaved soil (20.51%); and infested tubers, infested soil (24.13%); infested tubers in infested soil seemed to have been most severely infected. The clean tubers in autoclaved soil showed symptoms in one stand (0.53%), which might have been due to cross infection.

In another experiment, at the same time, in artificially inoculated tubers and soil, symptoms appeared on stands from tuber-inoculated treatments earlier (45 days after planting) than in soil-inoculated treatments (60 days), hence the difference in the degree of infection at the termination of the experiments (75 days) (Table 5).

Table 3. Comparison of leaves of the cultivar Obunaenyi after inoculation with isolates, singly and in combination.[a]

Inoculation	Mean % of leaves infected	Mean % of petioles infected
Colletotrichum	16b	16de
Colletotrichum, *Botryodiplodia*	54a	68c
Colletotrichum, *Fusarium*	18b	36d
Colletotrichum, *Fusarium*, *Botryodiplodia*	58a	60c
Fusarium	0bc	0e
Botryodiplodia	16b	18de
Distilled water	0bc	0e

[a]Means among organisms within each inoculation not followed by the same letters along the vertical column are significantly different (Duncan's multiple range test (P = 0.01)).

Table 4. Number and sizes of lesions produced on inoculated leaves by different isolate combinations.

Inoculation	Lesions/leaf[a]	Size of lesions[b] (mm)
Colletotrichum	5	0.1–4
Colletotrichum, *Botryodiplodia*	14	0.5–15
Colletotrichum, *Fusarium*	6	0.2–3
Colletotrichum, *Fusarium*, *Botryodiplodia*	12	0.1–20
Fusarium	0	0
Botryodiplodia	3	0.1–3
Distilled water	0	0

[a]Average of 50 leaves.

[b]Measurement of 100 lesions per treatment; lesions produced by the combinations measured as much as 15 and 20 mm in diameter.

Table 5. Effect of tuber and soil inoculation with *Colletotrichum* sp. on percent infection.

Days from planting	Infected plots (%)[a]		
	Tuber inoculated	Soil inoculated	Control
30	0	0	0
45	10	0	0
60	25	5	0
75	40	20	0

[a]All values based on six replications.

The ability of anthracnose organisms to persist on the host debris was substantial (Table 6). The results showed that all parts of the host (leaves, petioles, vines) harbour the pathogen(s), but the petiole and vine harbour more of the inoculum than do the leaves. One stand was infected in the control probably because of cross infection.

DISCUSSION

There is an indication from field symptoms that the rate and extent of disease development are characteristic for the pathogen–host environment. The yam vine grows continuously during the rainy season, even though there is premature abscission of early attacked leaves; the whole stand does not die immediately, as new leaves always emerge to nourish the plant. When adverse environmental conditions operate, however, even the young stands die when attacked.

There have been conflicting reports on results obtained from inoculating *Colletotrichum* sp. on host plants. For instance, whereas Jones and Vaughan (1921) obtained positive results on leaves and stems of pea (*Pisum sativum*) inoculated in the field with *Colletotrichum pisi*, Antonova (1940) stated that infection of pea seedlings was secured with difficulty and only in the presence of wounds. The fungus *Colletotrichum phomoides* has long been considered a wound pathogen on ripe tomatoes. Arthur (1885) and Halsted (1892) were able to transmit the disease from one ripe tomato to another only by wounding the inoculated fruits, but Doolittle (1943) stated that *C. phomoides* can infect unwounded tomatoes. Our results confirm that the *Colletotrichum* sp. isolated from lesions on *D. alata* can infect unwounded leaves, although wounded leaves are more susceptible. Infection was more severe on the lower leaf surfaces than on the upper because of easy entry through stomata that exist only on the abaxial surface of water yam; however this organism has been found to penetrate intact cuticle.

Table 6. Infection (% of stands) by transmission through debris (vines, petioles, leaves).[a]

Source	Mean % of stands infected	Mean % no. of petioles infected/ stand	Mean % of leaves infected/ stand
Leaf litter	35b	0.35b	1.06
Wood shavings	5bc	0b	0.05bc
Petiole and vine mulch	65a	3.1a	3.15a

[a]Means followed by the same letter along the vertical column are not significantly different; by Duncan's multiple range test (P = 0.01) for all values.

C. gloeosporioides has been implicated as the causal agent of the anthracnose of water yam, although Jackson and Newhoot (1978) implicated both *C. gloeosporioides* and *R. solani*. Our isolation and inoculation experiments, however, showed that, although *Colletotrichum* sp. may occur as an independent pathogen on leaves, it does not produce serious disease on petioles and vines (Table 3). Also, *B. theobromae* exists as an independent pathogen on yam leaves without producing anthracnose symptoms. The fact that *B. theobromae* was constantly associated with *Colletotrichum* in the field and in serious infections suggests that *Colletotrichum* is a weak parasite and only becomes very active in association with one or more of the isolated organisms.

Therefore, *Colletotrichum* sp. on water yam is not unlike many other anthracnose organisms. For example, *C. coffeanum* is found on living as well as moribund twigs of coffee, but the primary predisposing factor for the dieback is premature leaf fall due to *Hemileia vastatrix* (Mayne 1935). Roberts (1918) isolated *G. cingulata* commonly from apple stem cankers caused by other pathogens; the cotton anthracnose organism (*G. gossypii*) produces more numerous and more typical lesions when associated with the angular-leaf spot organism, *Phytomonas malvacearum* (Weindling and Miller 1941); and *C. gloeosporioides* commonly occurs on citrus without becoming an active parasite (Clausen 1912).

To control anthracnose of water yam, one must consider the inoculum source. From our results, it appears that both tuber-borne and soil-borne inocula are etiologically important. Although either source contributes to the early phase of the disease syndrome, the data on tuber and soil, artificial and natural infections suggest that tuber-borne inoculum could be more important (Table 4). The explanation could be that in inoculated tubers, the organism is probably well established even in

sprout initials, whereas in soil inoculation, the soil acts as a barrier, thereby delaying infection. Another important source of inoculum is the yam debris (infected vines, petioles, and leaves). Results from this study show that infected yam parts can be sources of inoculum (Table 6). The organisms involved in the disease syndrome can survive the Nigerian seasons, perhaps as spores, in the infected debris from the previous season's crop. The vines and petioles are a more durable source of inoculum than are the leaves, probably because they decay more slowly. It is very likely that new infection in the field during the next rainy season is initiated not only from planting materials (tuber setts) but also from soil or plant debris.

Tubers may become contaminated in the field during harvest, mostly through debris and be stored with the inoculum and replanted in the next planting season. Clearing debris after harvest and sterilizing tuber setts with a suitable chemical and perhaps rotating crops would reduce the disease incidence in the field.

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STRATEGIES FOR PROGRESS IN YAM RESEARCH IN AFRICA

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The various problems confronting yam production in Africa are highlighted, and research strategies are suggested for solving these problems. The problems of laborious planting and harvesting can be solved through mechanization. Staking, with its high labour consumption, should be discontinued and agronomic research done to make yam yield well without staking. Researchers can tackle the weed problem by developing a herbicide package that requires no supplemental weeding. The research strategy for yam breeding should aim at types with ovoid tubers, thick tuber periderm, high yield, good disease resistance, a high multiplication ratio, and the ability to yield well without stakes. The strategy for reducing storage losses should include selections of cultivars that have thick periderms and store well at temperatures of 0–10°C. Also the development of economic processed forms of yam will lessen the need to store the fresh tuber. Certain social phenomena peculiar to yam in Africa now threaten the implementation of the research strategies suggested. The most crucial of these phenomena is the lack of will on the part of governments and research agencies to execute yam research. Since the problems associated with yam will remain, unless tackled, this lack of will must be reversed.

Mise en évidence de divers problèmes limitant la production d'ignames en Afrique et stratégie de recherche proposée pour leur solution. Les travaux pénibles requis pour la plantation et la récolte peuvent être allégés par la mécanisation. Le tuteurage si exigeant en main-d'oeuvre devrait être supprimé et des recherches agronomiques effectuées dans ce but. A cause de sa sensibilité aux mauvaises herbes, un traitement global herbicide devrait être déterminé afin d'éliminer les sarclages; la stratégie de recherche pour la sélection d'ignames devrait être orientée sur des types à tubercules ovoïdes, à périderme épais, à rendement optimal, à taux de reproduction élevé et possédant une bonne résistance à la maladie et la propriété de croître sans tuteur. La stratégie de réduction de perte en cours d'entreposage devrait porter sur la sélection de cultivars à périderme épais qui se conservent bien à des températures de 0 à 10 °C. De même, de nouveaux traitements économiques devraient être mis au point afin de réduire le stockage de tubercules verts. Cependant, la mise en oeuvre des stratégies de recherche proposées ci-dessus pour l'Afrique est compromise par diverses attitudes sociales vis-à-vis de l'igname dont la plus grave est le refus de la part des gouvernements et des agences de recherche de poursuivre des études sur cette plante. Il faut donc corriger cette situation pour solutionner les problèmes relatifs à la culture de l'igname.

The yam is the agricultural economist's nightmare. The most critical problems in yam production today are those concerned with the economics of production. Broadly stated, these problems are high-labour input, the low yield per unit of input, and inadequate preservation facilities for the harvest. Research strategies for yam must, inevitably, have the objective of solving these problems so that, ultimately, a greater quantity and better quality of yam can be available to the consumer at a lower price.

The main labour-consuming aspects of yam production are planting, weeding, staking, and harvesting (Onwueme 1978a). The laboriousness of planting arises from the fact that in the traditional setting, both the land preparation and the planting are done by hand or with hand tools. The research strategy with respect to planting should therefore be to intensify efforts toward the complete mechanization of planting. The shift from hand-made mounds to machine-made ridges for yam production in many parts of Africa has already resulted in some labour savings. Research is going on in various locations to devise machinery that will ridge, place the sett, and cover up all in one operation.

Yam harvesting in Africa today is done almost entirely with hand tools. It is not only labour-consuming but also tedious. This is so for several reasons. First, the yam tuber is usually stored for several months. To avoid bruising the tuber and, hence, to maximize shelf-life, the farmers must exercise special care when lifting and handling the tuber. Second, the preference for large tubers

among African yam farmers and consumers implies that the mean depth from which the tuber must be extracted is great, with attendant increases in the time needed for harvesting. Third, most yams tend to respond to improved cultural practices by increasing the mean size (weight) per tuber rather than the number of tubers. Thus, modest improvements that have been made in cultural practices at the farmer's level have, paradoxically, increased the depth of tuber penetration and, therefore, increased the difficulty of harvesting. Fourth, some farmers practice double harvesting in which each plant is harvested twice, first about 3 months before senescence and then again after senescence. It has been amply demonstrated (Onwueme 1977a,b) that this practice does not result in a higher total tuber yield for the season; yet it demands more than double the time and effort needed for single harvesting.

The research strategy for yam harvesting, as that for planting, should be toward development of a mechanical yam harvester. Progress in this direction will probably depend on selection of cultivars with ovoid shape and thick skin, the breakdown of the preference for large tubers so that small mechanically harvested tubers can be economic, and the discontinuation of double harvesting.

Staking in yams has been shown to be beneficial (Waitt 1960; Chapman 1965; Lyonga et al. 1973), particularly in the humid tropics where insolation is low. However, staking is costly, laborious, and difficult to mechanize (Onwueme 1978c). Moreover, with increasing deforestation, wooden stakes are becoming scarce. One approach is to improve the system of staking (Campbell 1967; Fiji, Department of Agriculture 1979) — for example, the introduction of a trellis system. A second approach (Onwueme 1978a, b) is based on the belief that even the trellis system is expensive (40% of total production costs in Fiji) and that the ultimate solution to the staking problem is to eliminate staking from yam production. Once the decision has been taken that staking must go, all that is left is to determine, through agronomic experimentation, how to obtain the maximum possible yields from unstaked yams. It is important, of course, that the amount saved by the elimination of stakes exceeds any reductions in yield.

The obvious research strategy with respect to weed control in yams is the search for appropriate herbicides. This search has been rendered unusually difficult by certain peculiarities of the yam crop. First is the long period from planting time to emergence. This period can range from 1 to 4 months and means that a herbicide applied at planting may have lost much of its effectiveness by the time the yam emerges, whereas a herbicide applied just before emergence must be able to cope with the weeds that emerged since planting was done. Second, for normal commercial plantings (utilizing heads, middles, tails, and wholes), emergence is extremely staggered, and there is a wide time gap between the early and late emergers. It is impossible to pinpoint a time of emergence for the plot (except in a mathematical sense) so that one cannot easily plan a herbicide application to occur just before emergence. Third, yam cultivars are characteristically slow in producing leaves after emergence, and the ability of the crop to cover the ground is limited, the herbicide effect often wearing off before good groundcover is attained. Fourth, yam is a long-season crop, and there are few herbicides whose effect can persist for the duration of the yam-cropping season.

Herbicides that have been recommended for yam include diuron, linuron, and ametryne (Kasasian and Seeyave 1967; Renault and Merlier 1973; Akobundu 1977), but most workers recommend a supplementary hand weeding late in the season when the herbicide effect has declined. This situation is not satisfactory. The ultimate strategy should be to develop a herbicide package that constitutes a single herbicide application that is effective for the season. Considerable progress has been made at the University of Ife, Nigeria, in combining such a herbicide package with yam production without staking (Onwueme and Fadayomi 1980; Oriuwa and Onwueme 1980).

Some of the problems of yam that cannot be solved through cultural manipulation must be solved through plant breeding and selection. The overall strategy for a crop improvement program for yam should be to provide cultivars that embody the maximum number of desirable traits. As with most other crops, such traits would include high yield, disease resistance, and good culinary quality of the harvested product. For yam, specifically, such traits should also include a tuber that is ovoid and has a thick periderm to minimize harvesting injury and improve storability; a relatively high protein content; and ability to yield well even from small setts (i.e., a high multiplication ratio). The ability of the yam to yield well without support for its vines varies with cultivar and should be one of the objects of selection. In addition, attempts should be made to identify cultivars with a short growing season. This character would allow the farmer to grow another short-season crop (e.g., cowpea, maize) before or after the yam within the same cropping season; at present yam occupies the field for the entire cropping season.

One of the fundamental problems in yam

improvement is the degenerate sexuality of the plant. Flowering is irregular, hybridization is difficult, and seed production is sparse. Some species, such as *Dioscorea cayenensis*, usually produce only male flowers, and some cultivars never flower at all. With such species and cultivars, conventional breeding techniques break down, and the breeder is forced into the more esoteric realms of mutation breeding and pollen culture. Very few laboratories in Africa are capable of these techniques. Fortunately, however, a large pool of natural variability still exists for yams in Africa so that significant progress in yam improvement can yet be made on the basis of judicious selection alone.

In the area of crop protection, the African yam farmer has hitherto been fortunate in that most of the common yam diseases have not been debilitating. The situation seems to be changing, however, and a few diseases that can completely destroy the crop have been identified. The yam anthracnose or "scorch" is a good example. This disease has become quite prominent in *D. alata* in West Africa in recent years. Field resistance has been identified in some cultivars, and research is going on at various centres into methods of controlling the disease. For such a serious disease, control is essential; for less serious diseases, researchers should work to determine the extent of yield reduction due to the disease and to decide whether control measures would be economic.

Most yam producers store their yams fresh. A significant proportion of the harvest is invariably lost during storage. The main source of loss is through the attack of diseases and pests; other sources include sprouting, respiration, and dehydration.

The problem of storage losses in yams calls for an integrated research strategy starting from the field and ending on the dining table. In the field, the yam must be harvested with as little bruising as possible. Mechanical harvesting, if practiced, must be preceded by selection of cultivars with appropriate tuber characteristics such as a thick periderm and ovoid shape. Prestorage treatments, such as curing or pesticidal dips, for the tubers have had some success (Adesuyi 1973) and could be further explored. The use of gamma irradiation of the tubers to prolong storage life has been reported (Adesuyi 1973, 1976) and holds much promise for the future.

Investigations into the best environmental conditions for prolonged yam storage have been hampered by the fact that at temperatures lower than about 10°C, stored yams degenerate and turn brown. Yet at 10°C, microbial activity, tuber respiration, and sprouting are still high enough to threaten storability. Perhaps the strategy here should be to look for cultivars that can store at just above 0°C without turning brown. At such a temperature, the main factors leading to storage loss will be effectively contained.

Still another strategy for reducing storage losses in yam is to develop storable processed forms so that only a small fraction of the harvest need be stored fresh. Such processed forms are not only less prone to spoilage but also less bulky and, therefore, easier to store and to transport. Various kinds of yam flour that reconstitute into a paste similar to pounded yam have been tested in African markets. Most of them are certainly more convenient than making pounded yam from fresh tubers, but their production cost has been rather high. Efforts in this direction should be encouraged so that consumers can have dry, storable products that reconstitute, with minimal effort, into any of the whole array of yam dishes that can be prepared from the fresh tubers.

Progress in yam research and production in Africa will depend on an integration of the various strategies that have already been suggested. However, there are three social phenomena associated with yam that tend to override the foregoing considerations, and, indeed, threaten the implementation of rational research and production strategies. A higher group of strategies must, therefore, be fashioned to overcome these social constraints.

The first of these social phenomena is that, in most parts of Africa, there is a marked consumer preference for large tubers. This preference affects various facets of yam production to a degree not generally realized. Indeed it casts a long, lingering shadow over the entire production process:

- Large tubers only can be grown from large setts, which have lower multiplication ratios than do small setts (Onwueme 1978b). Thus, the prevailing problem of low multiplication ratio in yams generally is further exacerbated.
- Large setts planted to produce large tubers produce plants with extensive shoot systems (Onwueme 1972). Such shoot systems tend to need vine support for optimum leaf display; otherwise the leaves shade one another.
- Large tubers tend to heave and be exposed when produced on the flat or on low ridges. Mounds, which can be made as high as needed, are the ideal land preparation for producing large tubers. Thus many traditional farmers, with an eye for large tubers, have continued to grow their yams on unmechanizable mounds, despite the availability of mechanized ridge making.
- Large tubers penetrate the soil to a greater

mean depth than do small tubers. Harvesting is, therefore, more tedious, and the chances of the tubers being bruised are much greater. The bruises render the tuber prone to rotting during storage.

- The prospects for mechanical harvesters for yam are diminished if the production target is the large tuber. It is much easier to design a harvester for the shallower, less-fragile, small tubers than for the large tubers that now command the market premium.

Thus, the consumer preference for large tubers has repercussions from planting through storage. The strategy for dealing with this social phenomenon lies in prosecuting yam research vigorously because the preference for large tubers will probably break down in the face of advances in yam research. When the production (including harvesting) of smaller tubers is fully mechanized and made less laborious, such tubers will be so much cheaper than large tubers that consumers will be forced by economics to reconsider their preferences. Also if consumers get most of their yams as processed material, the size of the tuber from which the material originated will be irrelevant.

The second social phenomenon associated with yam in Africa is that even where research strategies have led to new methods, farmers resist innovations. True, there is farmer resistance to innovation in any crop, but, for yam in Africa, this resistance attains a level bordering on hostility. The main reason for this seems to be that many yam species are indigenous to Africa, and yam cultivation has more or less evolved here through the generations. Thus, traditional yam farmers consider themselves, not the researchers, to be the experts in yam production. For nonindigenous crops like cocoa or rice, farmers are willing to listen to researchers and adopt innovations, but, for yam, African farmers think it should be the other way round. With persistence, and demonstrably better methods, researchers should eventually be able to overcome this problem.

The third and potentially most damaging social problem confronting yam research and production is that many research agencies increasingly lack the will to undertake yam research. This is true in Africa as well as elsewhere. This situation arises mainly because yam is an extremely difficult crop to work on. Institutions and governments are more inclined to spend their money on crops where quick results can be had. Even individual researchers prefer to work on crops that are less intractable. The continent of Africa, for example, is replete with maize, rice, tomato, and cowpea breeders who can grow two or three experimental generations each year and, furthermore, can benefit from large pools of information collected on these crops in the developed countries. In comparison, how many yam breeders are there in Africa, which produces 98% of the world's yams? Very few. Very few, indeed, have ventured to burn their fingers on a crop with a long-growing season, irregular sexuality, and for which there is a dearth of information. The irony of the present situation, however, is that yam will continue to remain intractable unless somebody devotes enough research attention to it. The problems will not go away unless they are tackled. The ultimate strategy for progress in yam research in Africa, therefore, is to have the will to do yam research. Without this strategy, all the other strategies are inconsequential.

STUDY OF THE VARIABILITY CREATED BY THE CHARACTERISTICS OF THE ORGAN OF VEGETATIVE MULTIPLICATION IN *DIOSCOREA ALATA*

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Research into the variability created by the characteristics of the multiplication organ was carried out on *Dioscorea alata* cv Brazo Fuerte. The categories of plants studied, having the same genotype, had been grown from, on one hand, fragments of tubers all having the same weight (300 g), but taken from the top (FT), middle (FM), and base (FB), and on the other, from mixtures of fragments weighing 300 g (ME 300) and 70–120 g (ME 70-120). With regard to the level from which the fragments were taken, analyses show that there may be a gradient of germination speed from the base toward the top of the tuber. With regard to the average yield, there does not seem to be any significant difference between the plants grown from top, middle, or base fragments, but there is a gradient of dispersion of the yield along the tuber. This gradient is the reverse of the germination speed gradient. Concerning the influence of the fragments' weight, analyses show that fragments weighing 300 g germinate more rapidly than those weighing 70–120 g but that their heterogeneity of germination is greater. Further, plants grown from heavier fragments have a higher average yield and a greater homogeneity than those grown from fragments of lesser weight.

Les investigations sur la variabilité créée par les caractéristiques de l'organe de multiplication ont été réalisées chez *D. alata* cv Brazo Fuerté. Les catégories de plantes étudiées, ayant le même génotype, sont issues d'une part, de fragments de tubercules de même poids (300 g), mais provenant de la tête (FT), du milieu (FM) et de la base (FB) et d'autre part, de mélanges de fragments de 300 g (ME 300) et de 70 à 120 g (ME 70–120). En ce qui concerne le niveau de prélèvement des fragments, les analyses révèlent l'existence possible d'un gradient de vitesse de germination de la base vers la tête du tubercule. Sur le plan du rendement moyen, il ne semble pas exister de différences significatives entre les plantes issues des fragments de tête, du milieu et de base, mais par contre, un gradient de dispersion du rendement le long du tubercule. Ce gradient est l'inverse de celui de la vitesse de germination. Pour les influences de poids des fragments, les analyses montrent que les fragments de 300 g germent plus vite que ceux de 70 à 120 g, mais présentent une hétérogénéité plus grande. Par ailleurs, les plantes issues de fragments de plus grands poids ont un rendement moyen plus élevé et une homogénéité plus grande que celles issues de fragments de plus petits poids.

Tuber fragments are the most frequently used organs of multiplication in yam cultivation. But important variations in characteristics may be observed within a single clone, depending on whether the plants have been grown from fragments taken from the top, middle, or base of the tuber, and depending on the weight of the tuber fragments used. These variations were studied by Miège (1957), Degras and Mathurin (1974), and Ferguson et al. (1969).

In this report, we present the gist of the conclusions reached following a comparison, on one hand, of the categories of plants grown from fragments from the top, middle, or base of the tuber, and on the other, from plants grown from fragments weighing 300 g and 70–120 g.

To make up the various lots of seed fragments, 22 tubers of the cultivar Brazo Fuerte, species *D. alata*, having the same genotype and homogeneous weights, were chosen and fragmented. Three lots of fragments (300 g) gave the plants classified respectively FT (fragments from top), FM (fragments from middle), and FB (fragments from base). The fourth lot was made up of a mixture of top, middle, and base fragments, all weighing 300 g (ME 300), and a fifth lot of fragments weighing 70–120 g (ME 70–120). The experiment was begun in 1978. The experimental design was the block method. To compare the various categories of plants, we used variance analysis methods.

RESULTS

We made a comparison of the averages and the dispersion parameters that are the estimated coeffi-

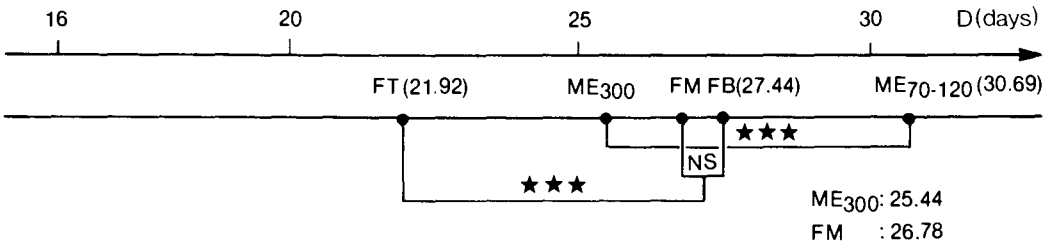

Fig. 1. *Germination time (days) and the relative positions of the averages for the various categories of plants.*

cient of variation and the residual variation. As far as the level of selection of fragments is concerned, comparisons deal with plants grown from fragments from the top, middle, and base, all having the same weight. In the study of effect of fragment weight, the comparison of average values and dispersions was made on plants grown from tuber fragments weighing 300 g (ME 300) and 70−120 g (ME 70−120).

GERMINATION TIME (FIG. 1)

Classing the three categories of plants by average values gives an increasing order FT, FM, FB, with very highly significant superiority ($P < 0.001$) of FT over the group (FM, FB) and over FM. But by dispersion parameters the increasing order of homogeneity is FT, FM, FB.

Seed fragments taken from the top of the tuber germinate more rapidly than do those from the middle or base; however, germination is more homogeneous with fragments from the middle and base. This indicates the existence of a germination speed gradient along the tuber. The increasing order of average germination times for fragments of different weights is ME 300, ME 70−120, and is very highly significant. The estimated residual variation and coefficient of variation give an increasing order of heterogeneity ME 70−120, ME 300. In other words, fragments weighing 300 g germinate more rapidly than those weighing 70−120 g, but their heterogeneity is greater.

BASAL DIAMETER OF THE FIRST TWO STEMS (FIG. 2)

Classing by average basal diameters of the first two stems of plants gives the increasing order FB, FM, FT, with a significant superiority of FT over the group (FM, FB). Dispersion parameters give an overall increasing order of homogeneity FT, FM, FB. Plants grown from base fragments having the

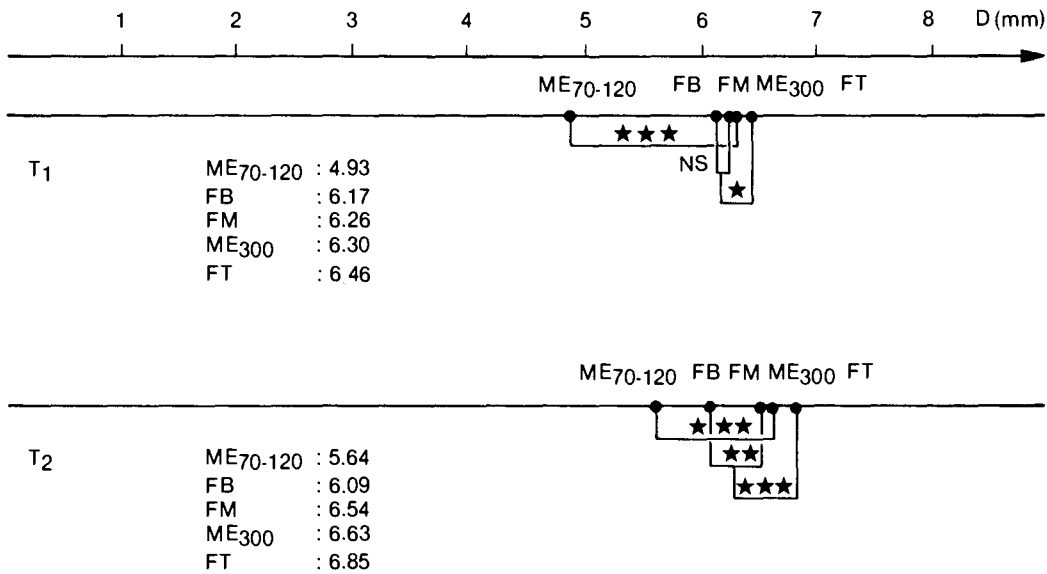

Fig. 2. *Basal diameter of first two stems and relative positions of the averages for the various categories of plants.*

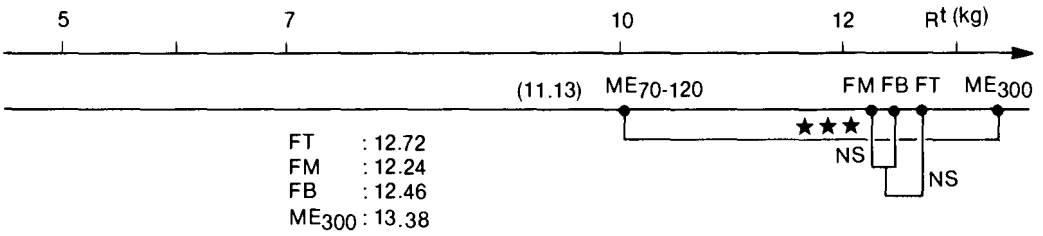

Fig. 3. *Yield/stalk and the relative positions of the averages for the various categories of plants.*

smallest stem diameters are more homogeneous than those grown from middle and top fragments. The averages for plants from fragments of different sizes are in the increasing order ME 70–120, ME 300, with very highly significant superiority of ME 300 over ME 70–120 for the two stems. Dispersion parameters show that the two categories of plants have the same degree of dispersion. But it is with the second stem that this characteristic is most dispersed.

YIELD (FIG. 3)

The average yield from plants grown from FB, FM, and FT is in the increasing order FM, FB, FT. However, neither the superiority of FT over the group (FB, FM) nor that of FB over FM is significant. Dispersion of values places the categories of plants in the increasing order of homogeneity FT, FM, FB, following the same dispersion gradient as that of the germination speed. Thus, with regard to the average yield, there does not seem to be any significant difference between plants grown from top, middle, or base fragments; on the other hand, there is a yield dispersion gradient along the tuber.

The average yield from fragments of different sizes places the plant categories in the increasing order ME 70–120, ME 300, with very highly significant superiority of ME 300 over ME 70–120. Dispersion parameters place them in the increasing order of heterogeneity ME 300, ME 70–120.

Plants grown from tuber fragments weighing 300 g have a higher average yield and greater homogeneity than plants grown from fragments weighing 70 to 120 g.

DISCUSSION AND CONCLUSION

Among the factors influencing variability, it must be noted that the level of selection and the weight of the fragments have been the subject of numerous studies. The characteristics given most attention are the germination time, the number of stalks and tubers per stalk, and the yield.

As far as germination time is concerned, all our results on various species and varieties are in perfect agreement. They show a gradient of precocity of germination along the tuber (Sawada 1952; Miège 1957; Mathurin and Degras 1974). The precocity of germination is also influenced by the weight of the tuber fragments used.

With regard to yield, some results show the advantage of using top fragments (Kinman 1921), others the slight superiority of base fragments (Mathurin and Degras 1974). On the whole, the results are diverse and do not indicate any gradient along the tuber. Much depends on the species and variety under consideration. We note, however, that the homogeneity of the yield increases from the top toward the base of the mother-tuber from which the seed fragments are selected. The influence of the seed fragments' weight upon yield has been well researched. Miège (1957) showed that the optimum weight of seed fragments to be used in order to obtain a better yield varies according to species and variety and that the weight of the mother-tuber from which the fragments are taken also has some influence on the yield.

With regard to the number of stems and tubers per stalk, the results are varied, and the existence of a simple, direct relation between this characteristic and the level of selection is unlikely (Kinman 1921; Ferguson 1969). Nevertheless, it is possible to note a variation in the number of tubers harvested in relation to the level and size of the fragments (Mathurin and Degras 1974).

These results show that the choice of seed fragments is fundamental for the user whose objectives are germination that is either early or late, homogeneous or dispersed, and high yield of tubers.

This paper was originally French; with the author's permission, it was translated into English for inclusion in these proceedings.

GROWTH PATTERN AND GROWTH ANALYSIS OF THE WHITE GUINEA YAM RAISED FROM SEED

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Growth pattern of the white guinea yam, *Dioscorea rotundata*, raised from seed was studied between May and October 1978 by the method of growth analysis. Observations were recorded on the time course in dry weights of the various organs. Comparisons were made with the situation in plants raised from tuber. Derived data on growth parameters were compared with results obtained for some other tropical plants.

Étude effectuée au moyen d'une méthode d'analyse de croissance sur le cycle végétatif de l'igname blanche *Dioscorea rotundata* cultivée à partir de semences entre mai et octobre 1978. On a noté la durée de la formation des matières sèches des différents organes et des comparaisons ont été établies avec des plantes provenant de fragments de tubercules. Les données relatives aux paramètres de croissance ont fait l'objet d'études comparatives avec les renseignements concernant d'autres plantes tropicales.

As the white guinea yam, *Dioscorea rotundata*, occupies a special position in the diet of Nigerians, in particular, and West Africans, in general, it is important that its growth pattern be properly understood. Such an understanding will help in determining which components of the growth parameters account for optimal yield and what kind of environment fosters efficient growth.

Njoku et al. (1973) provided data on the pattern of growth and development in the Alafu variety of *D. rotundata* raised from tuber. Sobulo (1972) reported on the growth analysis of Atoja and Olonko varieties of *D. rotundata* also raised from tuber. The only reported attempt at studying the growth pattern of yam raised from seed was by Sadik and Okereke (1975a), but apart from seed germination, flowering pattern, and final tuber yield, no data were provided on other growth parameters of this plant.

Our study, therefore, has been to compare the growth pattern and growth analysis of *D. rotundata* raised from seed with the situation in plants raised from tuber.

MATERIALS AND METHODS

Seeds of *D. rotundata* cultivar Obiaoturugo, supplied by the National Root Crops Research Institute, Umudike, were dewinged and stored a minimum of 4 months so that their dormancy was broken naturally. Seed storage was in a desiccator at about 23°C in an air-conditioned room. We selected seeds for uniformity and sterilized them in 1% sodium hypochlorite. Ten seeds were sown on wet filter paper in petri dishes and were then kept in a dark incubator at 27°C for seed germination. Distilled water was added as necessary. Four-week-old, one-leaf seedlings were transplanted at 10-cm spacings into wooden boxes 90 × 60 × 20 cm that had been filled with a topsoil–organic manure mixture. The boxes were kept under shade in the department botanic garden and watered twice daily. At the two or three leaf stage, irregular plants were removed. For the first sampling, 15 seedlings were randomly selected, and the remaining plants were transferred to the greenhouse for a further 16 weeks.

Eight-week-old seedlings were transplanted into plastic 20 × 25 cm buckets filled with the soil mixture and grown in a greenhouse. The plants were watered twice daily and were supported by stakes by the 10th week. Plant samples were collected each fortnight. Maximum and minimum temperatures and relative humidity in the greenhouse were recorded daily. Light intensity was recorded at time of sampling. The experimental design was a randomized complete block, and sample size was 15 plants.

At each sampling, soil was removed from the roots with water. Each plant sample was divided into leaves, vine, roots, and the tuber (when present). Petioles were recorded as vine stem. For each plant sample the number of leaves, leaf area, length of main vine, number of branches, length of branches, number of nodes on the main vine and

branches, internode length of the main stem and branches, number of roots, mean length of roots (mean of the four longest roots), and their dry weights were recorded. Dry weights were determined after dehydration at 100°C for 48 h. Leaf area was determined by the paper-tracing-and-weighing method.

The primary data for leaf area and plant partition dry weights (without tuber dry weight) were used in the calculation of net assimilation rate (NAR), leaf area ratio (LAR), and relative growth rate (RGR) for the growth period. Also the leaf area : leaf weight ratio (LA : LW) was computed from the primary data for the growth period.

Net assimilation rate was calculated as: NAR = $([W_2-W_1]/[t_2-t_1])$ $([\log_e A_2-\log_e A_1]/[A_2-A_1])$, where W_1 and W_2 are the mean dry weights per plant; A_1 and A_2, the total leaf area per plant between two sampling times; t_2-t_1 is the duration in days between the initial (t_1) and final (t_2) sampling times.

Leaf area ratio (LAR) was calculated as: LAR = $\frac{1}{2}([A_1/W_1]+[A_2/W_2])$ $cm^{-2}g^{-1}$.

Two methods were used for calculations of the relative growth rate. One was: RGR = $([\log_e W_2-\log_e W_1]/[t_2-t_1])$ gg^{-1} day^{-1}. The other method was to find the product of NAR and LAR. The methods gave the same results, so the latter was adopted because it was faster.

The leaf area : leaf weight ratio (LA : LW) was obtained as the leaf area over the leaf dry weight.

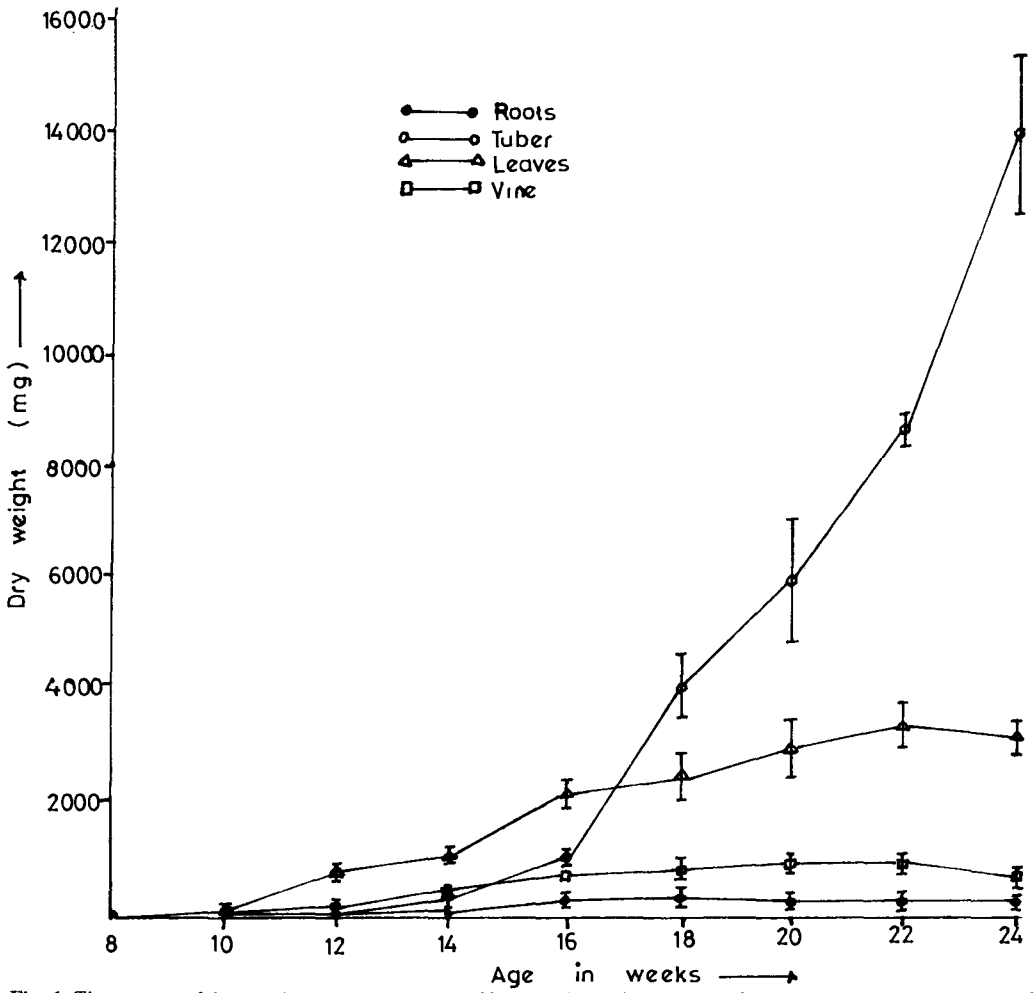

Fig. 1. *Time course of dry weights of various organs of* D. rotundata *raised from seed. Each point represents a mean of 15 plants; vertical lines represent ± standard error of the mean.*

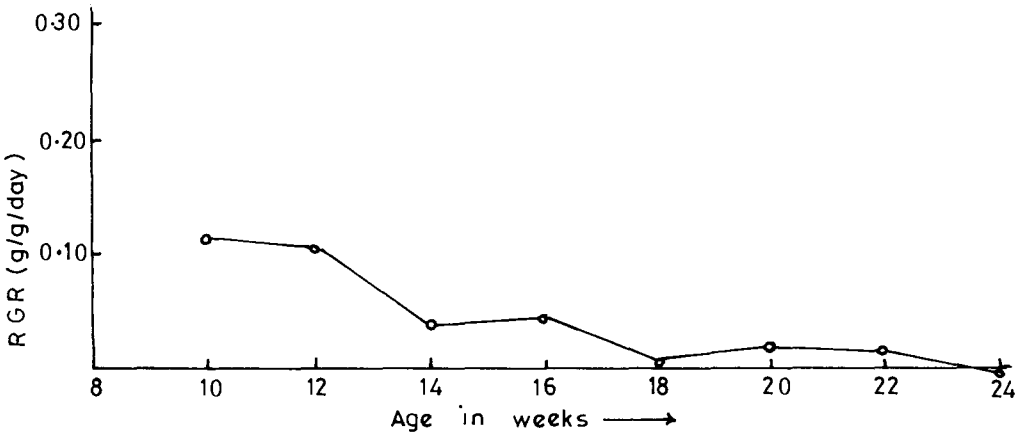

Fig. 2. *Variation in relative growth rate (RGR) with age of* D. rotundata *raised from seed.*

RESULTS

By the 8th week when the seedling had become properly established with two to three leaves, a prominent vine, and eight to nine roots, the leaves recorded the highest weight, and the roots recorded the lowest. Subsequently, there was a steady increase in the growth of these organs with time, the leaves maintaining the highest rate and the roots growing at the lowest rate (Fig. 1).

Growth of roots terminated earlier than did that of the other organs — between the 16th and the

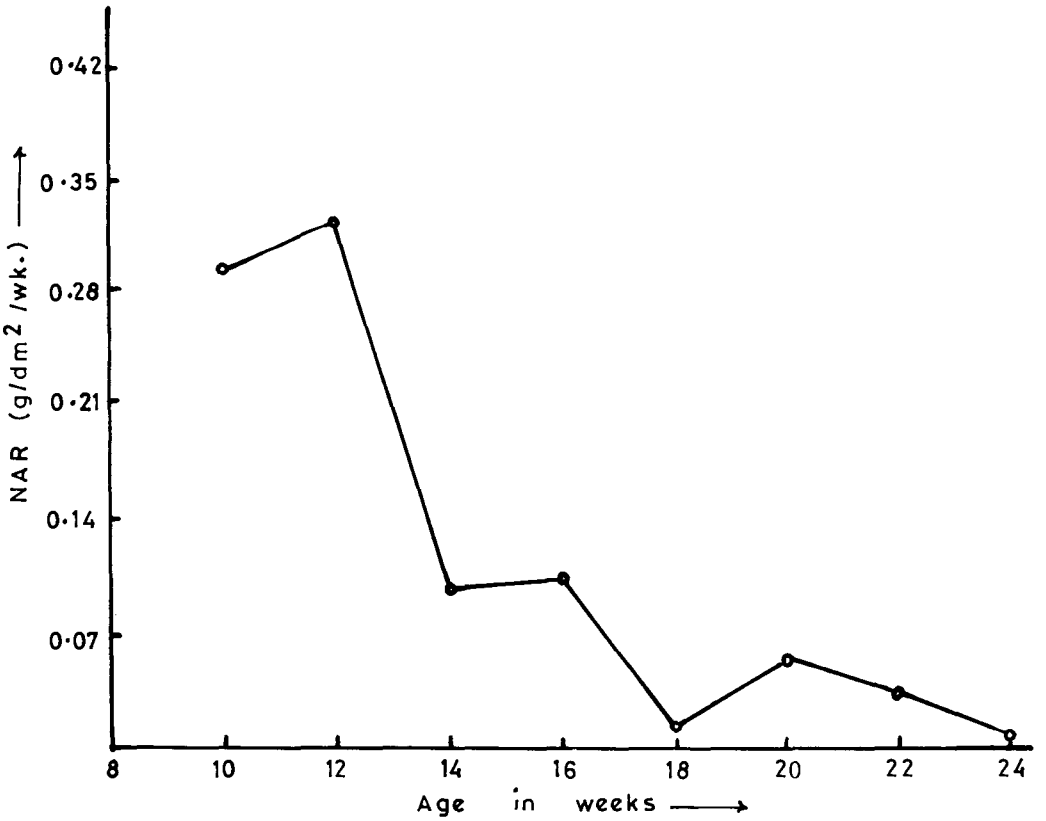

Fig. 3. *Variation in net assimilation rate (NAR) with age of* D. rotundata *raised from seed.*

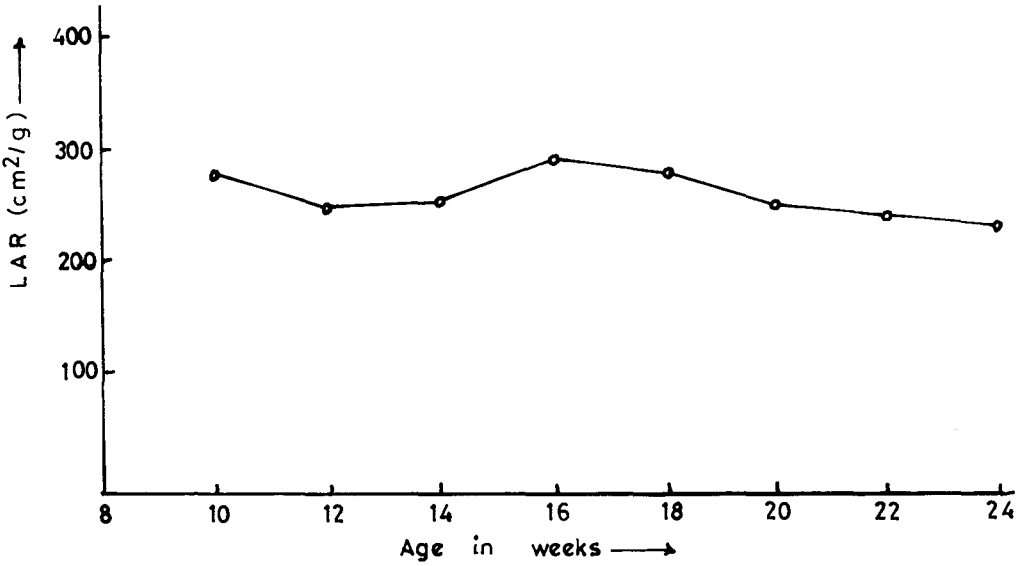

Fig. 4. *Variation in leaf area ratio (LAR) with age of* D. rotundata *raised from seed.*

18th week. Vine growth was also gradual but occurred at a much faster rate than did root growth and terminated much later — about the 22nd week. The leaves recorded the highest growth of the three organs, and the growth rate was rapid between the 10th and the 16th weeks.

Tuber was initiated by the 10th week and grew gradually between then and the 14th week. Rapid tuber growth occurred from the 16th week onward. The tuber continued to grow rapidly even when the other organs had either leveled off or declined in growth.

The trend was an apparent rhythm in the growth pattern of this plant. There is first the development of the vegetative organs — the leaves, vines (stem), and roots, with the leaves growing the fastest.

Growth Analysis

Relative growth rate (RGR)(Fig. 2), net assimilation rate (NAR)(Fig. 3), and leaf area ratio (LAR)(Fig. 4) all tended to decrease with time throughout the growth period. Net assimilation rate, however, seemed to correlate more with relative growth rate than did leaf area ratio.

Leaf area : leaf weight ratio (LA : LW)(Fig. 5) also tended to decline for most of the growth period (Fig. 6). From the 8th to the 12th week a very sharp decline occurred. There was, however, an increase in value between the 12th and the 14th weeks. Subsequently, there was a gradual decline for the rest of the growth period.

Discussion

The only reported attempt at studying the growth pattern of *D. rotundata* raised from seed was made by Sadik and Okereke (1975a). Seed germination, flowering pattern, and final tuber yield were the only parameters reported in their study. It is, therefore, difficult to make comparisons between their findings and our own. Our growth curves obtained for Obiaoturugo variety are in many ways similar to those obtained for plants raised from tubers of Alafu variety by Njoku et al. (1973); Sobulo (1972), on Atoja and Olonko varieties; and Campbell et al. (1962) on *D. alata*. As was the case with plants raised from tuber, our plants exhibited definite waves in organ development. Njoku et al. (1973) noted that up to about the 6th week the plants consist only of roots and stem and depend entirely on the old tubers. During this time, depending on the size of the mother tuber, the stem can attain considerable height and is bare of leaves, showing only rudimentary leaves that Waitt (1965) called cataphylls. The roots grow rapidly during this period, and the plant is established but not autotrophic. The situation was slightly different for our own plants raised from seed. There was rapid root and vine development and absence of cataphylls. Leaf development was already taking place, but rather slowly, as not more than two leaves were usually formed by this time. Also, the seedling was established but not autotrophic and depended on the endosperm for nourishment.

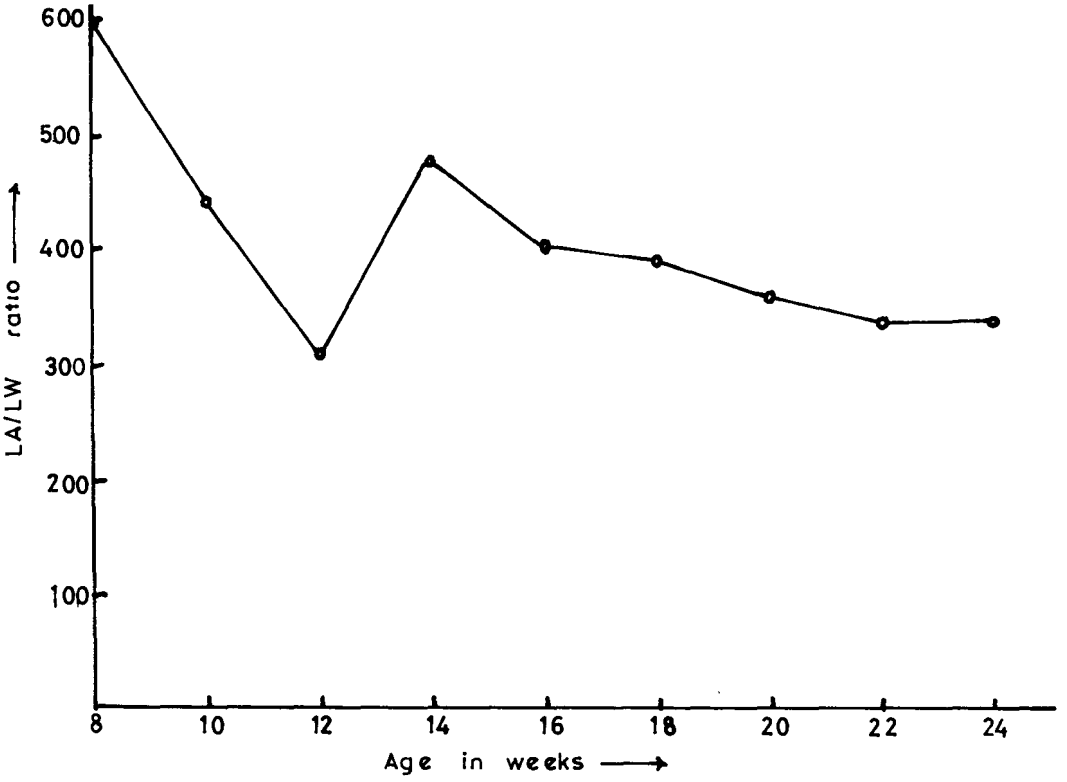

Fig. 5. *Variation in leaf area to leaf weight ratio (LA/LW) with age of* D. rotundata *raised from seed.*

Root growth in our plants occurred for a longer period than was the case for plants raised from tubers. Njoku et al. (1973) reported that most of the root is formed from material of the mother tuber and that growth has reached its peak before the plant becomes autotrophic. Our finding with plants raised from seed is that root growth continues long after the plant has become autotrophic. Njoku et al. had up to 20 main roots per plant, the longest reaching 250 cm. Thus, in their study, by the time the plants were leafy, the soil was interlaced with long, shallow roots, and root competition was already serious. They explained that this competition probably plays a role in bringing about early cessation of root growth. We obtained a maximum length of 21.5 cm. The nature of the original planting material must be responsible for the difference in root growth between the two groups. The seed endosperm does not have the capacity to produce roots at the same rate as it is producing tuber. Our plants, therefore, must depend on the photosynthetic capacity of the leaves produced in reasonable quantity long after the plant has become autotrophic and, hence, the longer period of root growth. It is, however, noteworthy that, from the 14th week, the roots were distributed between the rhizome and the body of the tuber in our plants so that increase in number of roots must be due to those formed on the bulking tuber (Fig. 6). The fact that root dry weight leveled off by the 16th week despite the new roots formed on the bulking tuber suggests that senescence of old roots has set in by this time.

Duration of leaf growth in our plants was longer than that for plants raised from tuber. Leaves developed slowly during the time that plants raised from tuber were bare of leaves. When leaves are eventually formed by plants raised from tuber, the rate is much faster than it was in our plants. Although Njoku et al. (1973) reported rapid leaf growth by the 8th to the 10th week and, by the 14th week, leaf growth had slowed, our plants had two leaves by the 8th week and rapid leaf growth started by the 12th week. From Waitt's (1965) key there appears to be some variation in leaf growth between cultivars, explaining the differences in the two studies: We worked with Obiaoturugo variety, and Njoku et al. (1973) worked with Alafu variety. We

were unable to compare our results with Sobulo's findings for Atoja and Olonko (1972) because he sampled leaves and petioles together, whereas we did not include the petioles with the leaves.

Like plants raised from tuber, plants raised from seeds terminate stem growth because of senescence and death of the apex of the main vine and some branches. This senescence takes place before that of the leaves. Unlike the situation in plants raised from tuber, however, dieback of the main vine in our plants led to formation of more branches, perhaps, due to loss of apical dominance of the main vine.

Tuber was initiated by the 10th week in our plants, and this finding coincides with time of tuber initiation reported by Njoku et al. (1973) for plants raised from tubers. Oyolu (1961) reported tuber initiation by the 12th week, which is later than was observed in our plants or those of Njoku et al. It is not easy to compare these findings with those of Sobulo (1972) because he made his first sampling about 17 weeks from time of planting by which time the tuber might have been long initiated. He also sampled tuber and roots together; so it must have been difficult to make out exactly when tuber was initiated. Differences in time of emergence from plant to plant in his study also would have made it difficult to determine the age of his plants at any particular time. It is, however, possible that variation in time of tuber initiation resulted from varietal differences.

In our study, tuber yield had declined markedly by the last sampling (14 g dry weight for the 24th week), whereas Njoku et al. (1973) had more than 400 g in the 24th week. Sadik and Okereke (1975a) had tubers weighing more than 500 g (fresh weight) after 12 months growth of plants raised from seeds but had much higher values for plants raised from tubers. Waitt (1961) obtained tuber fresh weight of 450 g after 2 years' growth from plants raised from seeds.

It is noteworthy that in our plants tuber was still bulking at a high rate even after leaf growth had dropped due to senescence. This finding contrasts

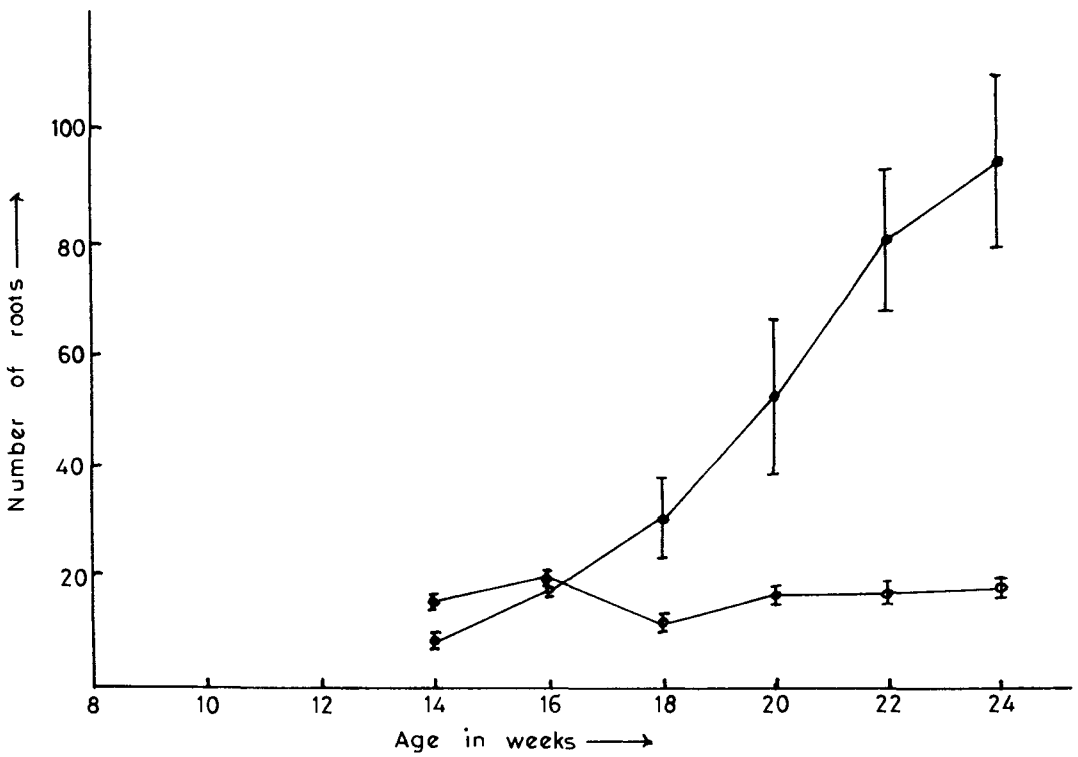

Fig. 6. *Distribution of roots to rhizome and tuber with age of* D. rotundata *raised from seed. Each point represents a mean of 15 plants; vertical lines represent ± standard error of the mean.*

sharply with observations made by Njoku et al. on individual plants, which showed reduced tuber growth due to leaf senescence. This is not easy to explain, but it is likely that the leaves remaining on our plants still had enough photosynthetic capacity to channel substantial amounts of assimilates toward tuber bulking. It is also likely that, because vine and root growth had ceased, all the available photosynthates were being directed toward tuber bulking — hence, the high rate of tuber growth. These arguments are further supported by the fact that leaf area : leaf weight ratio (LA : LW) continued to drop at this time (Fig. 5). It is known that a decrease in LA : LW indicates a higher photosynthetic efficiency of the leaf (Eze 1973), and, hence, its continued drop in value indicates that the leaf is still efficient in photosynthesizing and mobilizing assimilates toward tuber bulking.

Moisture content of tuber decreased (Fig. 7), whereas percentage dry weight increased (Fig. 8) — a situation also reported by Sobulo (1972) for plants raised from tubers. Sobulo quotes Brown as saying that moisture content of some varieties of yams was lowest 2 months before maturity. Our results show that the pattern of tuber maturity in yam raised from seed is the same as that raised from tuber.

Our mean NAR (net assimilation rate) of 11.63 g/m^2-wk(0.12 g/dm^2-wk) was rather low compared with the mean, 40 g/m^2-wk obtained by Njoku et al. (1973) for plants raised from tuber. Sobulo (1972) reported an NAR of 17 g/m^2-wk for Atoja variety of *D. rotundata*, whereas Chapman (1965) had 16 g/m^2-wk for *D. alata*. The available literature indicates that Goodall (1955), studying cocoa seedlings in Ghana, obtained the lowest NAR values so far reported for plants grown in the tropics. He had a mean NAR of 8.2 g/m^2-wk for seedlings grown in full daylight. Goodall (1950) also showed that during the first 30 weeks of growth under 20% of full daylight, cocoa seedlings had a mean NAR of 7.2 g/dm^2-wk. All other plants so far studied in the tropics have higher NAR values than our own. For example, Rees (1963) reported 23 g/m^2-wk for oil-palm seedlings in Benin; Njoku (1959), working with 10 West African herbaceous species at Ibadan, had values ranging from 53 to 152 g/m^2-wk; Okali (1971) working with tree seedlings and *Helianthus* had values ranging from 14.3 to 70.4 g/m^2-wk; and Blackman and Black (1959) had 69−152 g/m^2-wk for some tropical species.

Our mean leaf area ratio (LAR) of 258 cm^2/g was much higher than the value obtained by Njoku

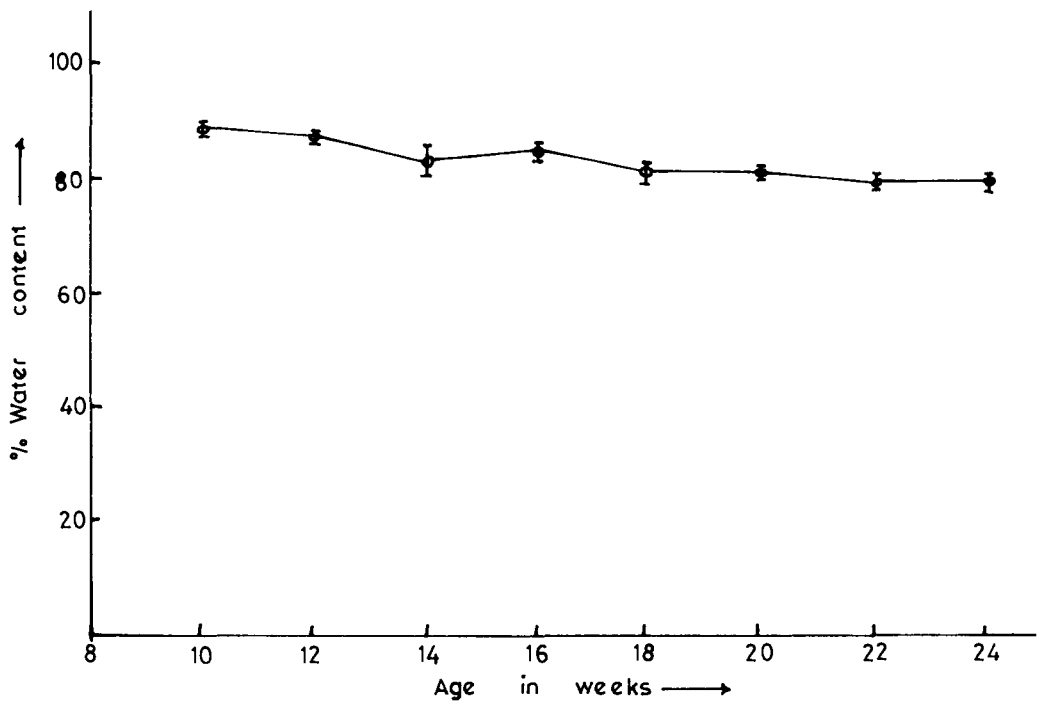

Fig. 7. *Variation in percentage water content of tuber with age in* D. rotundata *raised from seed. Each point represents a mean of 15 plants; vertical lines represent ± standard error of the mean.*

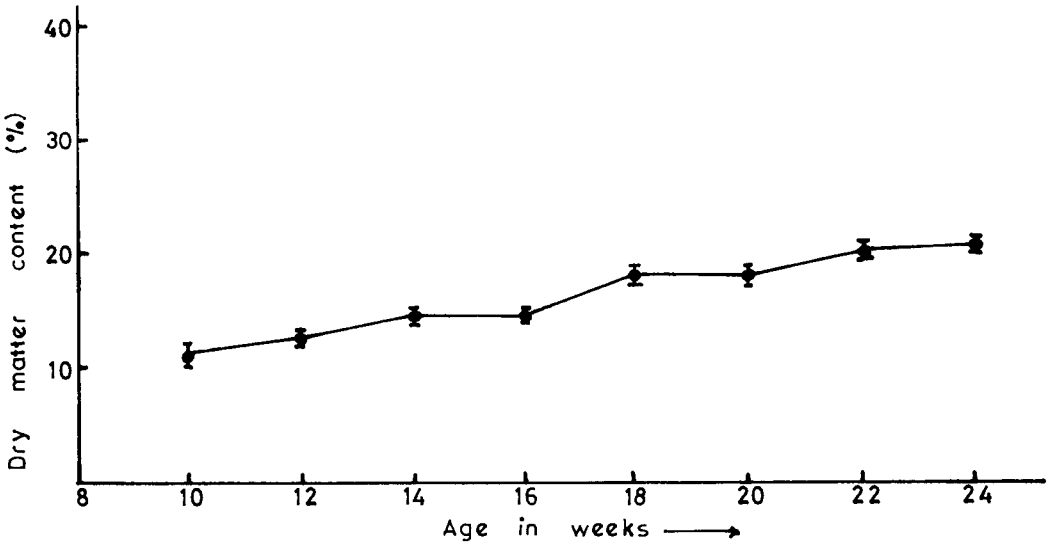

Fig. 8. *Variation in percentage dry matter content of tuber with age in* D. rotundata *raised from seed. Each point represents a mean of 15 plants; vertical lines represent ± standard error of the mean.*

et al. (1973) and only comparable with the highest value of 255 cm^2/g obtained in full daylight by Njoku (1959) for *Ipomoea purpurea*; and mean values of 246, 250, and 290 cm^2/g for plants from the genera *Chlorophora, Helianthus*, and *Terminalis*, respectively, by Okali (1971).

Our mean relative growth rate (RGR) was higher than values obtained by Rees (1963), Njoku et al. (1973), Njoku (1959), and Eze (1973) but lower than most of the values obtained by Okali (1971) for tree seedlings.

Since RGR is a product of NAR and LAR, the reasonably high value obtained for *D. rotundata* raised from seed as compared with that raised from tuber results from the high LAR, which compensated for the rather low NAR.

Heath and Gregory (1938) generalized that mean NAR is relatively constant for different species and for tropical and temperate climates. Also, Njoku (1959) noted that, on the whole, the variation of the NAR with time and between species is small under West African conditions. This relative constancy was suggested as being partially dependent on the fairly uniform climatic conditions throughout the year. The difference in NAR values between our plants and those of Njoku et al. (1973) does not support the view of relative constancy in NAR in the tropics. Our plants were grown between May and October 1979, whereas theirs from tubers were grown between May and December 1973 both at Nsukka. Any difference in weather conditions between the two periods in the 2 different years at Nsukka must have been insignificant. Eze (1973) also noticed that NAR values between *Helianthus annuus* and *Phaseolus vulgaris* in Freetown were not constant between March and December 1969. Eze's findings support our own and contrast with those of Heath and Gregory (1938) and Njoku (1959).

Blackman (1962) showed that, when light level was reduced from full daylight to a quarter daylight, the NAR was depressed but the LAR increased. Njoku (1960) reported that, in general, the relationship of both the NAR and LAR to light intensity follows a logarithmic trend, the NAR decreasing and the LAR increasing logarithmically with decreasing light intensity. Okali (1972) showed that shading induces a decrease in NAR, which is not fully compensated by the concomitant increases in LAR, so that little seedling growth can occur under a forest canopy. It is pertinent, therefore, to attribute our rather low NAR values to some degree of shading imposed on the plants by the greenhouse where they were grown, in which light intensity ranged between 11 000 and 14 000 lux whereas light intensity outside ranged from 15 500 to 22 000 lux during the growth period. Warren Wilson (1966) attributed high NAR to high levels of solar radiation. Eze (1973) obtained higher NAR values in the dry season than in the rainy season and suggested that the rainy season depresses growth mainly through light reduction by cloud cover. Evidence abounds, therefore, to justify the hypothesis that the reduced light intensity

reaching our greenhouse plants accounts for our NAR, which was lower than that obtained for plants raised from tuber and grown outside. It is also possible that mutual shading arising from the production of new leaves as the plant ages accounts for the decrease in NAR. As the architecture of our plants was similar to that of plants raised from tubers, one would have expected similar trends. The fact that NAR in our plants was depressed to a much larger extent than was that of plants raised from tubers can only be accounted for by the difference in light intensity of the environments of the two groups.

A reduction in light intensity to the extent recorded in the greenhouse during this study should cause a definite rise in LAR in view of Blackman's (1961) findings that 25% reduction of full daylight increases LAR. Our very high mean LAR of 258 cm^2/g justifies this finding.

Blackman et al. (1955) have shown that leaf area is positively correlated with temperature, but they were unable to demonstrate any significant effect of temperature on NAR in *H. annuus*. Eze (1973) indicated that LAR (as well as LA : LW) in both *H. annuus* and *P. vulgaris* is negatively correlated with light and positively correlated with temperature. Maximum and minimum temperatures remained relatively constant throughout our study. LAR also showed little variation, whereas NAR decreased; LAR, therefore, correlated positively with temperature in this study — a finding that lends support to the findings of Blackman et al. (1955) and Eze (1973).

Pandey et al. (1978) found significant genotypic differences in LAR in *Vigna mungo*. It is possible that the differences between our plants and those raised from tubers are a consequence of varietal differences.

ARTIFICIAL POLLINATION, POLLEN VIABILITY, AND STORAGE IN WHITE YAM

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We pollinated white yam (*Dioscorea rotundata*) by hand using three techniques: a camel-hair brush was used to pick up and transfer pollen from anthers to stigmas of open female flowers; a pointed tip of a bamboo splinter was used to excise anthers from open male flowers and to insert them into open female flowers; and pollen suspension in an aqueous culture medium was dropped through a blunt-tipped 1–2-ml syringe into open female flowers. The brush technique was most effective and yielded 147 seeds per day compared with 49 and 11 for the splinter and the dropper techniques, respectively. The potentially high seed yield per day of the brush method resulted mainly from the high percentage of fruit set (27.8) and the large number (450) of flowers that could be pollinated in a day.

When short-term pollen storage was studied, we found that the loss of viability was twice as rapid under field conditions as it was under room conditions where temperature and relative humidity (RH) were constant. Storage of pollen was compared at 26–30°C and 10°C and at 75–85, 80, and 0% RH; viability was best preserved at 10°C and 0% RH. No correlation was found between fruit set from hand pollinations and in vitro germination with stored pollen from 20 genotypes ($r = -0.12$). The results of these studies should improve the effectiveness of controlled pollination in white yam and the short-term storage of pollen for crosses between parents whose flowerings do not coincide.

La pollinisation artificielle d'ignames blanches (*Dioscorea rotundata* Poir.) a été effectuée selon trois procédés: récolte du pollen des anthères de fleurs femelles avec un pinceau de poil de chameau; excision des anthères de fleurs mâles et transport sur des fleurs femelles à l'aide d'une baguette de bambou à fine pointe; injection dans les fleurs femelles de pollen en suspension en employant une seringue épointée de 1–2 ml. Les opérations avec le pinceau ont été les plus efficaces, donnant jusqu'à 147 semences par jour comparées à respectivement 49 et 11 pour la baguette et la seringue. La supériorité du procédé réside principalement dans le grand nombre de fleurs (450) qui ont pu être pollinisées en une journée et du pourcentage élevé de la nouaison (27,8). En étudiant le stockage à court terme du pollen, on a découvert que la perte de principes actifs était deux fois plus accélérée dans les champs, où les fluctuations de la température et l'humidité relative (HR) étaient plus accentuées que dans un établissement. L'étude comparative portait sur trois semaines d'entreposage à 26–30° et 10 °C à un taux d'humidité de 75–85, 80 et 0%. Les meilleures conditions de conservation du pollen sont: température de 10 °C et hygrométrie de 0%. On n'a trouvé aucune corrélation entre les fruits provenant de la pollinisation artificielle et la germination en laboratoire lorsqu'on a utilisé du pollen entreposé de 20 génotypes. Les conclusions de ces études permettront d'améliorer l'efficacité de la pollinisation contrôlée chez l'igname blanche ainsi que l'entreposage à court terme du pollen destiné aux croisements entre parents dont la floraison se produit à différentes périodes.

Yams are staple food crops in West Africa, which produces 75% of the world's annual output (FAO 1976). White yam (*Dioscorea rotundata*) is preferred in West Africa and is more widely and intensively grown than are other yam species.

The successful germination of open-pollinated seeds and the establishment of seedlings in the field have permitted yam improvement through conventional breeding (Waitt 1958; Doku 1961; Sadik 1976). Now that seedling populations are segregated, breeders have a wide variation from which to select. However to produce the desired progenies, they must use controlled pollination and, thus, urgently need techniques for artificial pollination.

Flowering of white yam is limited to June through September at Ibadan, Nigeria. The flowers are insect-pollinated. Male plants generally begin flowering 2–3 weeks earlier than do female plants, and if flowering of the male and female parents does not overlap, pollen must be stored and kept viable if it is to be used in crosses.

Our 2-year study (1978–79) at IITA, therefore, was to find suitable methods of artificial pollination and short-term storage of pollen.

MATERIALS AND METHODS

HAND POLLINATIONS

Each year, 500-g tuber setts were planted in March and the resulting plants individually staked. (2.4 m). No fertilizer was applied. Three pollinating techniques were tried. A small camel-hair brush with few bristles was used to pick up pollen from preharvested anthers and transfer it to stigmas of open female flowers; the pointed tip of a bamboo splinter was used to excise anthers from open male flowers on detached spikes and insert them into open female flowers; and a suspension of pollen in Brewbaker and Kwack (1963) aqueous culture medium was sucked into a blunt-tipped, 1–2-ml syringe, then dropped into open female flowers.

Fully developed female flowers were bagged and pollinated 4 days later when they opened. Pollinated flowers were then left bagged for 2 weeks. Mixed pollen collected from several clones was used for all hand pollinations. As control, some female flowers were bagged, left unpollinated, and then unbagged after 14 days. Other female flowers were left unbagged so that insect pollination could be effected.

Pollinated flowers and controls were checked for fruit set twice a week, and overall percentage of fruit set was determined ([fruits/flowers pollinated] × 100). For the controls, the number of flowers bagged but left unpollinated or the number of unbagged flowers were used as the denominator. We assumed each fruit has the potential to produce six seeds and, thus, calculated percent seed set ([seeds set/fruit × 6] × 100). We then estimated mean percent fruit and seed set for all spikes for the controls and pollination techniques using the percentages of individual spikes.

The three methods were compared with regard to cost of equipment, allowance for mixing pollens from different sources, appropriateness for single plant crosses, tedium encountered during use, efficient use of pollen, risk of flower injury, number of flowers pollinated per 4-h day, percent fruit set, percent seed set, estimated daily seed production, and viability of resulting seeds.

SHORT-TERM STORAGE OF POLLEN

To test the effects of various short-term storage conditions on pollen viability, we took cuttings with inflorescences from four genotypes and placed them under room conditions in a beaker of water. Immediately afterward, pollen was taken from recently opened flowers and germinated in a modified Brewbaker and Kwack (1963) culture medium in agar. Comparable inflorescences were left under field conditions and initial in vitro germination of pollen was also determined. Germination of pollen from flowers left under field conditions was tested after 1 day, and from those under room conditions after 2 days. The RH and temperature of the room and field were recorded.

To determine a suitable environment for storage we conducted a preliminary pollen-storage experiment at room temperature; the rapid loss of pollen viability suggested the need for reduced temperature storage as reported for many types of pollen. A repeat experiment was then conducted at two temperatures: 26–30°C (room) with 75–85% RH (open bottle), 80% RH (closed bottle), and 0% RH (over $CaCl_2$); and 10°C (refrigerator) with 80% and 0% RH. Two trials were started on 8 and 24 September 1979. Anthers, harvested from recently opened male flowers (between 12:00 and 14:00 h), were mixed and placed in small glass vials (35 × 10 mm). Each vial was put in a 35-ml bottle. Some bottles were left open; some covered; and some, with 7 g anhydrous calcium chloride ($CaCl_2$) in the bottom, were covered so that the RH was maintained at 0%.

Pollen from all treatments in each test was sown on the same agar medium in different sectors of the same petri dish. New medium was prepared for

Table 1. Fruit and seed set and germination of seeds resulting from three techniques of pollination in *D. rotundata*.[a]

Pollination technique	Flowers pollinated	Fruit set (%)	Seed set (%)	Seed germination (%)
Brush	1226	27.8 a	19.6 a	61.0 a
Splinter	226	18.2 a	25.0 a	47.4 a
Dropper	788	3.2 c	14.5 a	68.3 a
Unbagged control	2220	11.6 b	13.9 a	54.7 a
Bagged control	2497	4.3 c	22.8 a	49.2 a

[a]Means followed by common letter are not significant at 5%.

Table 2. Comparison of three artificial pollination techniques used in *D. rotundata*.

Feature	Pollination technique		
	Brush	Splinter	Dropper
Cost of equipment	Low	Least	High
Appropriate for single plant crosses	No	Yes	No
Allows for mixing pollen from different sources	Yes	No	Yes
Tedium encountered during pollination	Low	High	Moderate
Efficient use of pollen	Most	Moderate	Least
Injury to female flowers	Least	Most	Moderate
Flowers pollinated/day (4 h)	450	180	400
Seeds/day	147	49	11
Germination of seeds	Normal	Normal	Normal

each test. Afterward, the petri dish was kept at 26–28°C, and pollen germination was checked after 18 h.

Pollen Viability and Fruit Set

Pollen was collected from each of 20 clones; part of it was germinated in vitro and the remainder was used in hand pollinations. The percentage of fruit set was determined and its correlation with in-vitro pollen germination computed.

Results

Hand Pollinations

The brush technique gave the highest percent fruit set, although the results were not significantly higher than those for the splinter technique. These two techniques gave significantly higher fruit set than did the dropper and the controls (Table 1). The brush method was most efficient and the dropper, the least (Table 2). The brush technique gave 147 seeds/day; this was 3 times that for the splinter technique and 13 times that for the dropper.

Short-Term Storage of Pollen

The overnight loss of pollen viability in the field was twice as fast as under room conditions (Table 3) probably because the RH and temperature fluctuations in the field were much greater than were those in the room (Fig. 1).

The curves of viability for each storage condition in the two trials of controlled environment were essentially similar (Fig. 2). At 10°C, loss of viability in pollen stored over $CaCl_2$ desiccant was slower than it was at 80% RH, and viability was maintained better at 10°C than at 26–30°C.

Pollen Viability and Fruit Set

There was no significant correlation between percent in vitro pollen germination and percent fruit set ($r = -0.12$, $n = 20$).

Discussion

Hand Pollinations

The effectiveness of a pollinating technique can be measured by its superiority over a bagged,

Table 3. Loss of pollen viability under room and field storage conditions in *D. rotundata*.[a]

Storage location	Storage conditions		Duration of storage (days)	% germination in vitro		% loss in viability
	RH (%)	°C		Before storage	After storage	
Field	49–94	26–36	1	47.1	28.3	39.9**
Room	78–83	31–32	2	35.4	22.1	37.6**

[a]** = significant at 1% level of probability.

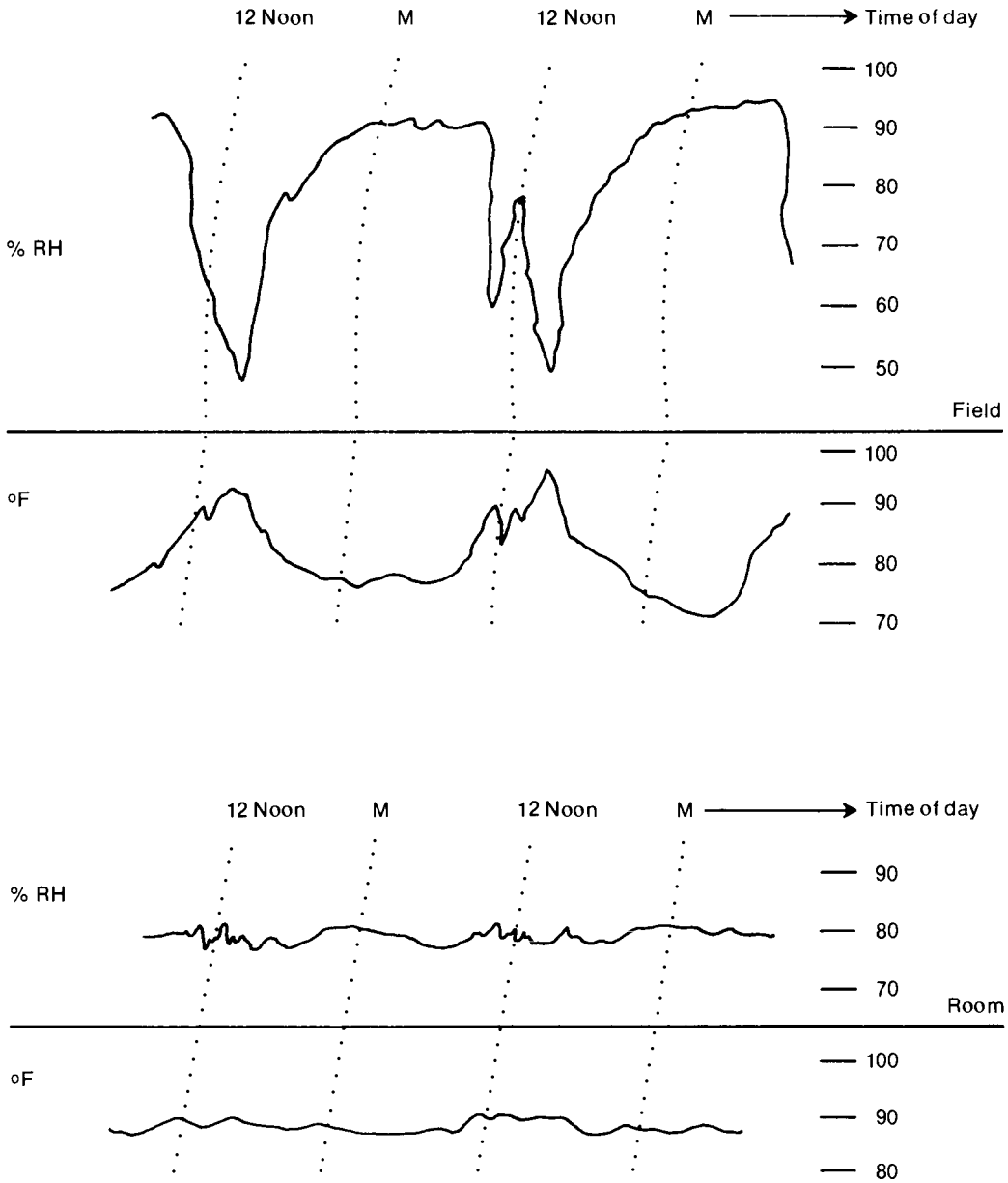

Fig. 1. *Fluctuation in relative humidity and temperature in a field and room used for overnight storage of pollen.*

unpollinated control. Thus, the dropper technique was not effective, its percent fruit set being very low. Its poor performance may have resulted from inadequate concentration of pollen in the suspension, failure of the pollen to contact the stigma due to surface tension of the droplet, or reduced pollen germination as a result of anaerobic conditions within the droplet.

The splinter technique was the only technique appropriate for single plant crosses. However, it was wasteful in that detaching inflorescences results in the loss of immature flowers. This waste is especially important when a clone with few flowers is repeatedly needed as a male parent.

The brush technique with 27.8% fruit set was the most effective and compared favourably with the

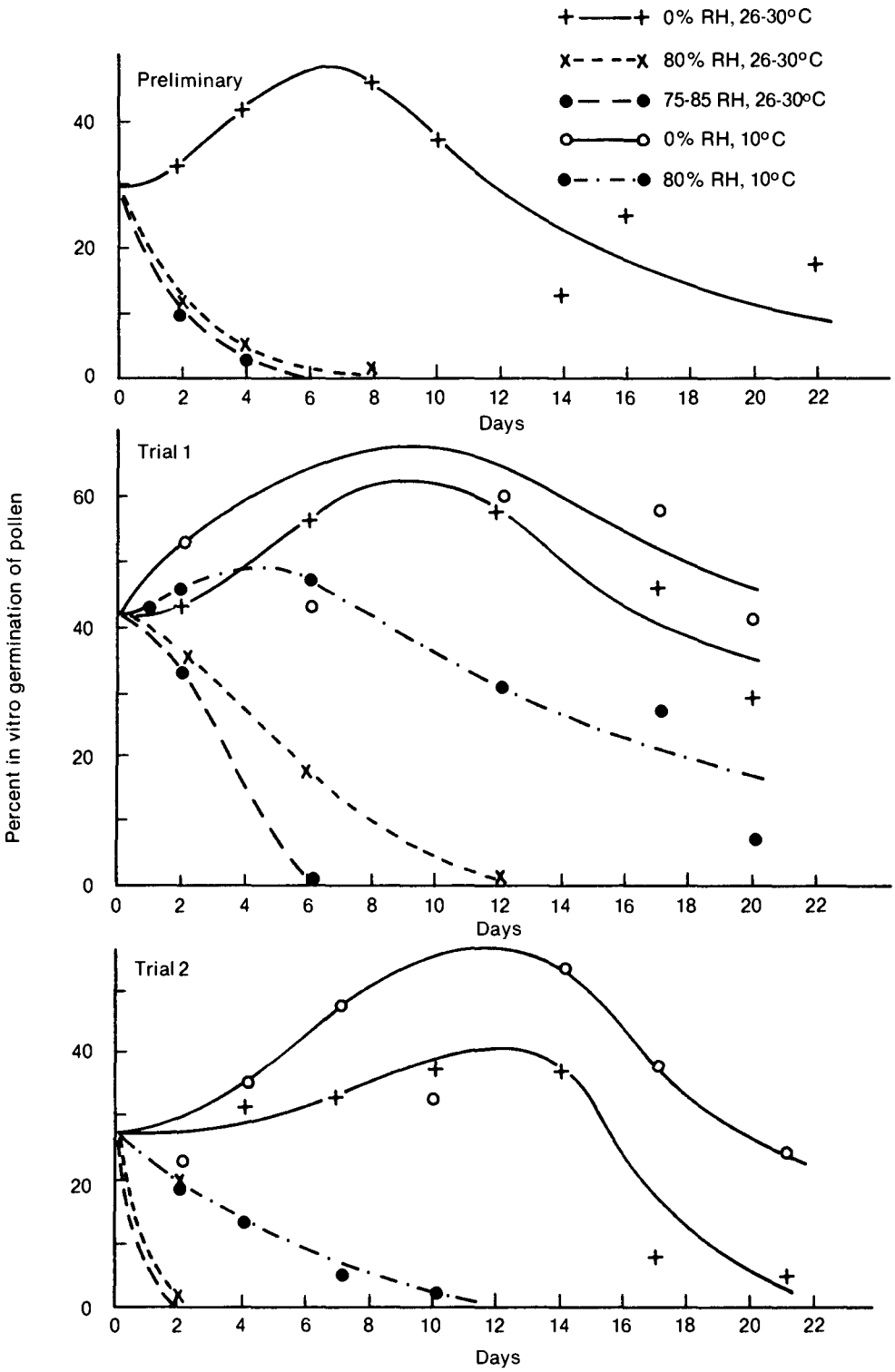

Fig. 2. *Pollen viability under short-term storage of* D. rotundata.

results (23.3–33.0%) obtained with the needle and modified forceps methods previously used at IITA (1974, 1975, 1976, 1977). It was superior to these methods when other important aspects such as tedium and efficient use of pollen were considered. The greater seed production achieved by the brush compared with the splinter and dropper techniques resulted mainly from the greater number of pollinations per day and higher percent fruit set. Percent fruit set with the brush technique was more than twice that of the insect-pollinated, unbagged control.

Thus, the brush technique is the most satisfactory method of artificial pollination when mixed pollen from several genotypes is used. It can also be used to supplement insect pollinations in isolated crossing blocks.

Short-Term Storage of Pollen

The rapid loss of pollen viability in the field is largely due to fluctuations of RH and temperature. In less variable conditions, loss of viability is slower. These results agree with the report of Stanley and Linskens (1974) that pollen cannot tolerate extreme moisture variations because they induce alternate high and low metabolic activity.

The better maintenance of pollen viability observed under reduced RH and temperature agrees with results obtained with the pollen storage of many species (Stanley and Linskens 1974). As has also been shown elsewhere, desiccation proved to be more important than reduced temperature.

The increase in viability observed in pollen stored over desiccant suggests that freshly collected pollen from recently opened male flowers has a high moisture content and may require drying to improve its viability. Male flowers of white yam open fully only under warm, sunny conditions. This may be a within-plant mechanism to expose pollen grains to drying conditions. The pollen grains adhering to hairs of thrips that visit flowers have high moisture content but may dry as the insects fly or move from flower to flower.

Pollen Viability and Fruit Set

The lack of relationship between in-vitro pollen germination and fruit set indicates that there is no correspondence between in-vitro and in-vivo assays. The high in-vitro germination of a pollen sample may not imply the production of seed when used for pollination (Johri and Vasil 1961), as environmental and genetic factors have more influence on percent seed set than does viability per se.

IMPROVING THE IN-SITU STEM SUPPORT SYSTEM FOR YAMS

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In vast areas of the humid and subhumid tropics, yam vines are supported on the in-situ pruned or killed stems of shrubs or trees selectively retained at bush-fallow clearing. Under natural regeneration, the land is left fallow for 5 or more years before it is cleared and selected stems are used as yam support. With selected species such as *Leucaena leucocephala* and *Glyricidia sepuim*, in-situ stem supports are available in 1–2 years. Arranging support plants in rows allows for uniform yam fields instead of the haphazard arrangement associated with bush fallow. An intensive system based on a rotation of maize and yam within the support species is envisaged.

Dans une grande partie des tropiques humides et sub-humides, la tuteurisation des ignames est effectuée à l'aide de branches d'arbustes mortes ou de celles qui ont été gardées lors de la préparation des terres en jachères. Les terres sont généralement laissées au repos pendant cinq ans au plus et les tuteurs choisis sont le fruit de la régénération naturelle. Certaines espèces tel *Leucaena leucocephala* et *Glyricidia sepuim* peuvent en 1 ou 2 ans seulement servir de tuteurs sur place. En les plantant en rangées, les champs d'ignames seraient plus uniformes et moins désordonnés que ceux où la plantation est faite au hasard de la pousse des tuteurs. On envisage la culture intensive par rotation du maïs et de l'igname en fonction des tuteurs naturels.

The survival of yam as an important tropical staple remains in doubt mainly because the crop is labour-intensive and production costs are high (Campbell 1967; Coursey 1967b). Although nearly all aspects of yam production require high labour inputs, staking or providing support for the climbing vines is often singled out as a major hindrance to production expansion. In addition to its high labour demands, vine support calls for materials such as bamboo or small stems, which are often scarce and expensive. Yams grown without support yield significantly less than do supported ones (Coursey 1967b); yet over a large section of the yam-growing regions of West Africa, the world's leading yam-producing area, many farmers grow yams without support. The farmers are aware of the higher yield derived from supported vines, but most cite shortage of labour and scarcity of stakes as being responsible for the decline in the supporting of vines.

In the more humid regions, vine supporting remains a common practice. In these regions, weed control problems and leaf and stem disease associated with soil contact, in addition to reduced yields, are a major deterrent to supportless yam culture. In areas where staking is still common, the stakes are obtained from the bush fallow in which small trees and woody shrubs are the dominant plant types. However, high population densities and the demand for more food have increased the area under cultivation and have reduced both the area and the duration of bush fallow. Consequently, many areas no longer produce the stakes commonly used for yam vine support. Farmers must transport staking material, usually bamboo poles, many kilometres to their farms. The resulting increase in production cost is reflected in an increased price for yams, which may render them less competitive with other starchy staples and, eventually, lead to reduced yam production. This gloomy prognosis may be avoided if a suitable remedy is found for the staking problem.

Though the problem of staking has been a long-standing one, little has been done to provide alternatives or less-expensive yam vine support methods (Campbell 1967; Kennard and Morris 1956). We have, therefore, directed our efforts to the problems associated with providing support for yam vines and some possible solutions.

VINE SUPPORT PRACTICES

Coursey (1967b) reviewed yam vine support practices, including use of:

- Trunks and stems of trees or shrubs in the bush

fallow; these are usually pruned of leaves and killed or suppressed from early regrowth by being burned at the base. A stem may support more than one yam vine.

- Tall economic trees that have not been burned; the yam vines are led to them by strings attached 3–6 m up the tree and close to the base of the yam vine. One tree usually supports many yam vines.
- Stakes of bamboo or wood; stake thickness ranges from 2 to 10 cm, with bamboo commonly being in the upper range. Heights also vary but are seldom less than 2 m or more than 5 m. Again, bamboos are usually the taller stakes. Stakes are often strengthened against storm damage, 3–4 being tied together at the top or opposite stakes in parallel rows being tied and linked together by slim horizontal poles.
- Stem residues of crops, especially stiff sorghum stems; these are usually used as stakes in the savannas of West Africa and are often cut and stored during the dry season. They are usually tied together at the tops for extra strength.
- In-situ crop-stem residues, especially tall varieties of sorghum; depending on the rainfall pattern, yams are planted in ridges along the bases of the sorghum plants, often before the sorghum is harvested. The sorghum shades the yam ridges, keeping them cool during the dry season and eliminating the need for "capping" or mulching. When the yam sprouts at the start of the rains, the sorghum stems are bent at about 1 m aboveground and sometimes interwoven into low trellises that are fairly resistant to wind damage and usually persist through the yam growing period.
- Live crops, usually in mixed stands or intercropping systems; the crops include maize, sorghum, okra, pigeon pea, cotton, and castor bean. Because these crops compete with yams, the yield from yams supported in this manner is usually poor.
- Trellises, usually of wood and bamboo; these may be high or low, the latter being seen often in compound gardens in savannas or near cities where poles are scarce. The wooden or metal poles and wire trellises (Campbell 1967) used in experimental stations have not been adopted by farmers in West Africa.
- Mesh wire fences (Kennard and Morris 1956); these have been used successfully with steroid yams but may not be economic with food yams.

Importance of Yam Vine Support

Staking remains the most popular method for yam vine support (Coursey 1967b) and, in most locations, the most convenient. Except in areas where staking materials are not readily available, staking is also likely to be the least expensive method. Because of its popularity, staking has been the focus of most research on yam support.

Staking, or other support for that matter, elevates the weak vine, exposes a greater leaf area to insolation, and consequently encourages greater photosynthesis (Chapman 1965). The greater the leaf spread, the higher the yield expectancy; thus supports such as wire netting, which allows for greater leaf spread or higher leaf area index, give higher yields than staking does. Staked yam yields more than unsupported yams, and, perhaps, poor weed control in unsupported plots has influenced the results.

Farmers in humid areas generally believe that better yields are obtained by using taller stakes. Coursey (1967b), citing work from Ghana, contended that extra tall stakes had no special advantage. Yields did not increase significantly when stake height increased from 1.7 m to 3.6 m; however, response to stake height may depend on cultivar (Coursey 1967b).

The literature, though limited, indicates a positive response to staking or, more generally, vine support. However, the extra benefits are important only if support use is economic.

The Special Significance of Yam

To many West Africans, yam is not just a starchy staple but a religious and cultural symbol whose significance is not fully understood outside religious circles of the tribes concerned. It should be noted that the religious practices occur mostly in the humid forest where yams, other starchy roots and tubers, and plantain are the major food. In drier regions where cereals are important, no special religious significance is attached to yams even where they are a dominant crop.

There is very little information on the interrelationship between humans and crops in these areas, but the origin and distribution of the major crops in regions may be important. For example, in areas where yam has religious significance, it was, at times, the only crop from which storable food was available during the dry season. Perhaps, by guaranteeing the people's survival, it has been given special status. In such regions, it is also a symbol of wealth.

The yam's status explains why many people believe that increased costs of staking may mean an increased yam price but may not significantly affect production even in the presence of cheaper starch substitutes. It is unlikely that substitutes will ever replace yam as culinary, cultural, and religious objects in West Africa.

NEW CONCEPTS IN STAKING

Among indigenous farmers, traditional yam supports are:

- In-situ stems from the bush fallow;
- In-situ stem residues of crops; and
- Stakes.

Investigations aimed at developing improved and inexpensive supports are directed toward the basic principles of these supports because of their popularity. Based on the in-situ stems from bush fallow, an in-situ support system was developed at IITA. At 1.5 × 1.0 m spacings the in-situ stems gave a lower yield (17 t/ha) than did conventional staking at 1.0 × 1.0 m spacings (26 t/ha), even though the emergence (70%) was slightly higher with in-situ stems (70% compared with 64%). No difference was observed when spacings were identical; at 1.5 × 1.0 m spacings, the yield for yams staked with in-situ stems was 20.7 t/ha and, for those on conventional stakes, was 20.6 t/ha. The major advantage was that suitable support stems were produced in a shorter time than they are produced by bush fallow. The shrub *Leucaena leucocephala* produced suitable support stems in 1–2 years, a relatively short period compared with the 5–7 years for naturally regenerated shrubs and trees in the bush fallow.

Leucaena leucocephala was also used in two other methods: as conventional stakes and as horizontal support. In the latter, the tops and smaller branches were thrown on the ground and the vines grew over them. In this method, stems too short for conventional stakes supported the vines and exposed larger leaf areas to sunlight. Yields from this method were not significantly different from those from crops grown with conventional stakes (1.61 tubers/hill and 25.5 t/ha compared with 1.44 and 25.9 for conventional stakes).

These systems should have impact in areas where population pressure has reduced the bush fallow to periods shorter than required for development of stems suitable for stakes. With suitable species, stakes could be produced on marginal land not suitable for crops. Trials in progress indicate that more than 20 000 stakes annually are obtainable from a single planting of *Leucaena leucocephala*. These quantities were obtained over a 3-year period from plots that have not yet shown signs of decline.

CONCLUSION

The problem of supporting yam vines may be solved by production of stakes from fast-growing shrubs. The stakes produced would be used in situ as is the practice in the traditional system of growing yams after bush fallow or cut and used as conventional stakes. If made into conventional stakes, the shrubs could be grown on marginal land in close proximity to yam fields. Properly developed, these systems offer inexpensive stakes and, thus, lower yam production costs.

YIELD AND SHELF-LIFE OF WHITE YAM AS INFLUENCED BY FERTILIZER

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Studies were undertaken to assess the influence of fertilizer nutrient elements (N, P, and K) on the yield and storability of tubers of the white yam, *Dioscorea rotundata*. The yam cultivar, Nwapoko, responded significantly to high rates of nitrogen (90 kg N/ha), low rates of phosphorus (30 kg P/ha) in soils low in these nutrients — an indication of the high nitrogen but low phosphorus requirements of the yam plant. Highest yields were obtained from the nutrient combinations of $N_{45}P_0K_{30}$, $N_{90}P_{25}K_{30}$, and $N_{90}P_{50}K_{30}$, which produced tuber yields of 42.65, 42.95, and 42.22 t/ha, respectively, or marketable tubers of 38.43, 34.03, and 34.28 t/ha, respectively, representing yield increases of up to 36.9% over the control plot. Loss in tuber weight during storage was not significantly affected by N, P, or K fertilization. However, high rates of nitrogen significantly increased the percent sprouting of stored tubers, and increasing rates of phosphorus and potassium tended to suppress sprouting and, thus, enhance the storability. It is indicated that P and K fertilizers applied to yams would enhance the storage life of the tuber up to about 3–3.5 months after harvest.

Recherches conduites sur l'évaluation de l'influence des éléments nutritifs de N, P et K sur la culture et l'aptitude à la conservation des tubercules de l'igname blanche *Dioscorea rotundata* Poir. Le cultivar Nwapoko répond bien à une dose élevée d'azote (90 kg/ha), à une dose faible de phosphore (30 kg/ha) dans des sols où il y a carence de ces éléments, signe des exigences de l'igname qui préfère des sols riches en azote et pauvres en phosphore. Les combinations $N_{45}PO$, K_{30} $N_{90}P_{25}K_{30}$, et $N_{90}P_{50}K_{30}$ ont donné les rendements les plus élevés, soit respectivement 42,65, 42,95 et 42,22 t/ha ou 38,43, 34,03 et 43,28 t/ha de tubercules de taille commerçante, ce qui signifie un rendement de 36,9% supérieur à celui de la parcelle témoin. Les apports de N, P et K n'affectent pas sensiblement la perte de poids chez les tubercules entreposés. Mais une dose élevée d'azote a augmenté considérablement le taux de germination en cours de stockage. Cependant, un pourcentage élevé d'azote a sensiblement augmenté la germination de tubercules stockés alors que le dosage plus élevé de phosphore et de potasse a éliminé la croissance des germes, ce qui augmente la durée d'entreposage des tubercules de trois et même trois mois et demi après la récolte.

Correct assessment of fertilizer input for optimum results constitutes a major problem in yam production. In subsistence farming, the yam has traditionally been the first crop in a rotation of newly cleared land or after a fallow; thus it has benefited from the natural fertility of the soil. In intensive agriculture, the same plots are cultivated more frequently so that nutrient removal from the soil through crop harvest is much greater than it was previously. Because yams make high demands on soil nutrients (Obigbesan et al. 1976; Obigbesan 1977), farmers in yam-growing areas need to supplement the natural fertility of the soil by applying mineral fertilizers. Another important aspect of yam production is postharvest storage. Many farmers still believe that fertilizers have a deleterious effect on the yam crop either by burning it or by rendering the tubers more susceptible to rot in storage. Although there have been several studies on the storage of yams, these have been scarcely related to fertilizer use (Coursey 1967a; Adesuyi 1973). The few reports available have indicated that nitrogen, phosphorus, and potassium fertilizers do not significantly affect the weight loss of tubers in storage (Umanah 1973; Lyonga 1976; Azih 1976). The aim of our study was to investigate the response of a popular cultivar of *Dioscorea rotundata*, to N, P, and K fertilizers and the effects of these nutrient elements on weight loss and sprouting of tubers during storage, as early sprouting nullifies the shelf-life of the tubers.

MATERIALS AND METHODS

The investigations were carried out at the International Institute of Tropical Agriculture from April 1977 through May 1979. The 1977 experi-

Table 1. Effect of N, P, and K on fresh tuber yield (t/ha) of white yam, Nwapoko cultivar, 1978.[a]

	P_0			P_{25}			P_{50}		
	K_0	K_{30}	K_{60}	K_0	K_{30}	K_{60}	K_0	K_{30}	K_{60}
N_0	31.37 gh	35.14 defgh	33.79 cfgh	39.87 abcde	31.75 fgh	31.11h	34.54 defgh	34.51 defgh	34.38 defgh
N_{45}	34.76 defgh	42.65a	37.49 abcd efgh	40.86 abcd	37.94 abcd efg	36.03 bcdefgh	38.10 abcdef	34.51 defgh	40.13 abcde
N_{90}	38.70 abcde	37.78 abcd efg	36.63 abcd efgh	41.08ab	42.95ab	39.78 abcde	35.62 cdefgh	42.22 abc	40.51 abcde

[a]Values with a common letter are not significantly different at a 5% probability level as determined by Duncan's new multiple range test.

ment (yams planted 18 April 1977 and harvested 14 November 1977) was considered preliminary, comprising an NPK factorial combination of four rates of nitrogen (0, 50, 100, and 150 kg/ha) and two rates of P and K (0, 50 and 0, 60 kg/ha respectively). In the 1978 trial, three rates of nitrogen (0, 45, and 90 kg/ha) as ammonium sulfate, three rates of phosphorus (0, 25, and 50 kg/ha) as single superphosphate, and three rates of potassium (0, 30, and 60 kg/ha) as muriate of potash were applied to Nwapoko, the cultivar tested. There were 27 treatments replicated three times in a randomized complete block design; plot size was 7 × 3 m. On 1 May 1978, whole small tubers (setts) of the yam cultivar, Nwapoko, weighing about 300 g, were planted on ridges at a spacing of 1 × 1 m. Plants were staked with a 2.5 m long split bamboo. Six weeks after being planted, plants were treated with fertilizer. The fertilizers were applied in a ring around each plant and then incorporated into the soil. Weeding was carried out manually as required. At harvest, about 7 months after the planting, total tuber fresh weight and marketable yield were determined. Tubers weighing less than 500 g, rotten tubers, and nematode-infested tubers were considered unmarketable.

For storage, 20 marketable tubers from each treatment plot were tied on racks in a traditional barn for 6 months. The average day and night temperatures in the barn were 35.0°C and 25.3°C, and the respective average relative humidities were 40% and 94%. Sprouted tubers were counted every 2 weeks, and the sprouting percentage was determined as the ratio of the number of sprouted tubers to the number of tubers left at the time of observation multiplied by 100. Rotten tubers were discarded every 8 weeks, and the remaining tubers were weighed. Percent weight loss was also determined — initial weight minus weight at time of observation divided by initial weight times 100 at 8, 16, and 24 weeks after harvest. Sprouts were removed after each recording.

RESULTS AND DISCUSSION

YIELDS AND YIELD COMPONENTS

Table 1 shows the effect of N, P, and K on fresh yields, which ranged from 31.11 t/ha to 42.95 t/ha. Table 2 shows the effects on marketable yield. The highest marketable yields represented increases of up to 36.9% over the control, unfertilized plants. It

Table 2. Effect of N, P, and K on marketable tuber yield (t/ha) of white yam, Nwapoko cultivar, 1978.[a]

	P_0			P_{25}			P_{50}		
	K_0	K_{30}	K_{60}	K_0	K_{30}	K_{60}	K_0	K_{30}	K_{60}
N_0	24.65d	27.24bcd	26.59bcd	34.54abc	26.79bcd	24.99bcd	27.62bcd	26.25bcd	25.78bcd
N_{45}	27.74bcd	38.43a	31.21abcd	33.87abcd	31.87abcd	26.19bcd	31.08abcd	27.84bcd	34.63ab
N_{90}	31.02abcd	31.68abcd	29.46abcd	33.14abcd	38.03a	30.00abcd	25.78bcd	34.28abcd	32.89abcd

[a]Values with a common letter are not significantly different at a 5% probability level as determined by Duncan's new multiple range test; each value is the mean of three observations.

Table 3. Effect of NPK on average tuber weight (kg/tuber) of white yam, Nwapoko cultivar, 1978.[a]

	P_0			P_{25}			P_{50}		
	K_0	K_{30}	K_{60}	K_0	K_{30}	K_{60}	K_0	K_{30}	K_{60}
N_0	1.97d	2.08d	2.12cd	2.55abcd	2.25cd	2.11cd	2.51abcd	2.00d	1.99d
N_{45}	2.43abcd	3.05a	2.38abcd	2.55abcd	2.42abcd	2.47abcd	2.65abcd	2.20cd	2.85abc
N_{90}	2.69abcd	2.47abcd	2.57abcd	2.67abcd	3.02ab	2.27bcd	2.16cd	2.50abcd	2.84abc

[a]Values with a common letter are not significantly different at a 5% probability level as determined by Duncan's new multiple range test.

Table 4. Effect of NPK on number of tubers per 100 plants of white yam, Nwapoko cultivar, 1978.[a]

	P_0			P_{25}			P_{50}		
	K_0	K_{30}	K_{60}	K_0	K_{30}	K_{60}	K_0	K_{30}	K_{60}
N_0	159	170	163	159	141	147	138	173	183
N_{45}	144	141	157	160	157	148	145	157	141
N_{90}	144	154	143	154	143	178	179	175	143

[a]No significant difference at 5% probability level as determined by Duncan's new multiple range test; each value is the mean of three observations.

was strikingly evident that the yield increases were due to increased tuber size and not due to the number of tubers (Table 3 and 4).

Doubling the nitrogen input from 45 kg/ha to 90 kg/ha doubled the yield increase (7.33 compared with the previous 3.39 t/ha); a phosphorus level of 25 kg/ha was more effective (8.5 t/ha yield increase) than the higher rate of 50 kg/ha (3.17 t/ha yield increase). This result indicates the high-nitrogen, low-phosphorus requirements of the cultivar in this soil (Table 5). Similarly, K applied at 30 kg/ha was more beneficial than were higher doses on this potassium-sufficient soil.

Nitrogen and phosphorus application resulted in significantly larger tubers (Table 6). The weight of marketable tubers was also significantly improved by phosphorus application at 25 kg/ha (Table 6). These results indicate the limits of the beneficial effects of the nutrient elements in yam production. High P and high K levels depressed both the total yield and the marketable tubers of the yam cultivar. Several workers (Rouanet 1967; Gooding and Hoad 1967; Lyonga 1976) have reported positive yield responses to fertilizer input on soils where the levels of N, P, and K were low. Obigbesan et al. (1976), Obigbesan (1977), and Young (1976) pointed out that soils with less than 0.1% N, less than 10 ppm P (Bray 1-P), and exchangeable potassium less than 0.15 me/100 g could be considered deficient and that positive responses of yams

Table 5. Limit of beneficial effect of each nutrient element on *D. rotundata*, 1978.[a]

	Fresh tuber yield (t/ha)	Increase in yield (Δt/ha)	Average tuber weight (kg/tuber)	Increase in tuber weight (Δkg/tuber)	Marketable yield (t/ha)	Increase in marketable yield (Δt/ha)
N_0	31.37 b	–	1.97 b	–	24.65 b	–
N_{45}	34.76 ab	3.39	2.43 ab	0.46	27.74 b	3.09
N_{90}	38.70 a	7.33	2.69 a	0.72	31.02 b	6.37
P_0	31.37 b	–	1.97 b	–	24.65 b	–
P_{25}	39.87 a	8.50	2.55 a	0.58	34.54 a	9.87
P_{50}	34.54 ab	3.17	2.51 a	0.54	27.62 b	2.97
K_0	31.37 b	–	1.97 a	–	24.65 b	–
K_{30}	35.14 b	3.77	2.08 a	0.11	27.24 b	2.59
K_{60}	33.79 b	2.42	2.12 a	0.15	26.59 b	1.94

[a]Values with a common letter for a nutrient and within a column and nutrient are not significantly different at a 5% probability level as determined by Duncan's new multiple range test.

Table 6. Effect of each nutrient on percent weight loss of tubers of *D. rotundata* cv. Nwapoko, during storage in 1978 (figures in parentheses are for 1977).[a]

	Weeks after harvest		
	8	16	24
N_0	26.68 (5.40)	55.20 (31.64)	63.63 (62.27)
N_{45} (N_{50})	32.48 (7.09)	56.89 (29.81)	64.24 (50.79)
N_{90} (N_{100})	19.32 (7.28)	46.85 (27.41)	60.47 (61.92)
(N_{150})	– (6.48)	– (28.74)	– (56.14)
P_0	26.68 (5.40)	55.20 (31.64)	63.63 (62.27)
P_{25}	29.32 –	53.71 –	63.63 –
P_{50}	20.17 (6.65)	47.00 (32.47)	59.93 (59.38)
K_0	26.68 (5.40)	55.20 (31.64)	63.63 (62.27)
K_{30}	34.79 –	60.11 –	69.76 –
K_{60}	27.47 (3.68)	58.44 (27.22)	68.24 (60.93)

[a]No significant difference among values of each nutrient as determined by Duncan's new multiple range test at a 5% probability level.

to fertilizer are likely in such soils. Our precropping soil data (pH 5.3, 0.99% organic C, 0.088% N, 6.8 ppm P, and K, 0.35 me/100 g) indicated nitrogen and phosphorus fertilizer applications could be beneficial but not potassium.

STORAGE

The effects of nitrogen, phosphorus, and potassium fertilizers on the percent weight loss of stored tubers are shown in Table 6. Compared with the percent from untreated plots ($N_0P_0K_0$), the nutrient elements (N, P, and K) applied at high rates tended to reduce the percent weight loss up to 16 weeks after harvest (Table 6), and this observation was also more or less valid for plants that received high fertilizer rates in the 1977 experiment (Table 6). However, the differences were, as determined by Duncan's new multiple range test, not statistically significant. Earlier investigators, Umanah (1973), Azih (1976), and Lyonga (1976) observed no effect of N, P, and K on weight loss of stored tubers.

The most important result of the storage studies was that increasing rates of nitrogen significantly increased the percent sprouting (Table 7). This N effect was more consistent in the 1978 results than in the 1977 preliminary studies. Differences between untreated and N-fertilized plants were significant up to 13 weeks after harvest (WAH). In contrast, the sprouting of tubers from P-fertilized plants was significantly suppressed up to 14 WAH. Although practically no differences were observed in K-treated and untreated plants in 1977, the 1978

Table 7. Effect of each nutrient on percent sprouting of tubers of white yam, Nwapoko cultivar, during storage in 1978 (figures in parentheses are for 1977).[a]

	Weeks after harvest											
	7 (8)		9 (10)		11 (12)		13 (14)		15 (16)		17	
N_0	15.97	(6.67)	27.40	(45.70)	61.14	(81.40)	75.56b	(91.49)	96.97	(98.33)	96.97	
$N_{45}(N_{50})$	16.55	(5.0)	24.98	(41.23)	73.04	(74.03)	89.28ab	(87.81)	94.87	(100.00)	100.00	
$N_{90}(N_{100})$	19.06	(15.18)	49.78	(54.12)	79.17	(77.63)	100.00a	(94.82)	100.00	(98.33)	100.00	
(N_{150})	–	(15.00)	–	(47.46)	–	(73.16)	–	(93.33)	–	(100.00)		
P_0	15.97	(6.67)	29.40	(45.70)	61.14	(81.40)	75.56	(91.49)	96.97	(98.33)	96.97	
P_{25}	12.67	–	29.31	–	65.95	–	93.05	–	95.01	–	96.97	
P_{50}	14.25	(3.33)	30.46	(35.96)	70.46	(71.49)	89.78	(86.58)	92.04	(98.33)	100.00	
K_0	15.97	(6.67)	29.40	(45.70)	61.14	(81.40)	75.56ab	(91.49)	96.97ab	(98.33)	95.01	
K_{30}	18.50	–	35.36	–	66.16	–	95.00a	–	100.00a	–	75.51	
K_{60}	7.41	(11.67)	18.75	(46.67)	48.64	(76.67)	67.91b	(95.00)	83.33b	(100.00)	97.44	

[a]Values with a common letter within a column are not significantly different at a 5% probability level as determined by Duncan's new multiple range test.

results showed that the sprouting during storage tended to be retarded in the tubers from plots fertilized with high K rates (Table 7) up to 15 WAH. It can, therefore, be inferred that P and K fertilizers applied to yams enhance the storage life of the yam tubers up to about 3–3.5 months after harvest.

CONCLUSION

The role of nitrogen in yam production is uniquely important. This study demonstrates that apart from increasing the total fresh tuber and marketable yields, nitrogen also promotes the sprouting of tubers in storage. Thus, farmers who apply heavy nitrogen doses for high yields have to sell their harvested tubers or process them early to avoid economic losses resulting from excessive sprouting. High rates of nitrogen application for high yields simultaneously provide means of hastening the sprouting and thus breaking the dormancy of the stored tubers. This fact may be useful for rapid multiplication of selected materials in breeding programs.

The results also indicate that optimum nutrient combinations reduce not only the percent weight loss in storage but also the percent of tubers sprouting during storage. For example, a farmer who wishes to reduce weight loss of tubers and who can either process or sell them soon after harvest would have optimum results with application of high-nitrogen fertilizer, whereas one who wishes to reduce sprouting and thus increase shelf-life of tubers would have better luck with low-nitrogen, high phosphorous, potassium fertilizers.

The tendency of the tubers of P- and K-fertilized plants to exhibit suppressed sprouting up to about 3.5 months after harvest needs further investigation and confirmation on other yam cultivars.

WEED INTERFERENCE IN WHITE YAM

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The effects of weed interference on the growth and development of white yam (*Dioscorea rotundata* Nwapoko cultivar) were evaluated in an alfisol (Apomu sandy loam) in Ibadan, Nigeria. The evaluation indicated that weed interference ranged from 4 weeks to full season. From planting date, yam was more affected by weeds between 10 and 22 weeks than at other times. At about 10 weeks, the shoot exhibits greater growth than do the other growth organs (phase II), and this growth phase persists to 14 weeks after planting. The growth phase predominated by increased tuber bulking (phase III) is from 15 to 22 weeks after planting. Reductions in dry-matter accumulation in the crop roots, vines, and leaves as well as reductions in the fresh tuber relative growth rate were closely correlated with percent reductions in fresh tuber yield. The time that weeds caused serious reductions in tuber yields corresponded to the time interval during which loss in the growth and development parameters indicated yield-reducing potential. The adverse effects of weed interference during growth from 15–22 weeks after planting (phase III) was 65% more than that caused by weeds during maximum root development (phase I) and was 36% more than that observed at 10–14 weeks after planting (phase II) in white yam. The critical stages for weed interference in yam synchronized with the growth phases when leaf development and tuber bulking were maximal. Adverse effects at a given phase tended to be carried over to subsequent phases.

Recherche sur l'incidence des mauvaises herbes sur la croissance et le développement de l'igname blanche (*Dioscorea rotundata* Poir. cv. Nwapoko) cultivée sur des alfisols (glaise sableuse Apomu) à Ibadan, Nigeria. Les résultats ont démontré que la durée de l'action des mauvaises herbes s'étend de 4 semaines à la saison entière. De la 10e à la 22e semaine après la plantation, au moment de la levée, l'igname a été plus affectée par les mauvaises herbes. A environ 10 semaines, les racines étaient beaucoup plus développées que les parties aériennes, phase II qui dure jusqu'à la 14e semaine. La phase III, de 15 à 22 semaines après les semis, est caractérisée par le développement des tubercules. La réduction des matières sèches tirées des racines, tiges et feuilles et du taux de croissance des tubercules a été évaluée par rapport à la proportion de baisse de rendement en tubercules. La période pendant laquelle les mauvaises herbes ont le plus contribué à diminuer le rendement en tubercules correspond à celle prévue par les paramètres de croissance et de développement. Les effets nocifs des mauvaises herbes au cours de la phase III, soit de 15 à 22 semaines suivant la plantation, ont été jusqu'à 65% supérieurs à l'incidence sur la phase I et 36% de plus que sur la phase II. La période critique des effets des mauvaises herbes sur l'igname blanche correspond aux phases de croissance, au moment de développement maximal des feuilles et des tubercules. Les effets nocifs subis au cours d'une phase donnée se répercutent sur la suivante.

Crop-yield reductions due to weed interference are proportional to the amount of water, light, and nutrients used by the weeds at the expense of the crop (Blackman and Templeman 1938; Hurst and Feltner 1966; Wiese et al. 1964) and to the extent of allelopathic influence of the weeds on the crops (Grummer 1965; Winter 1961).

Weed interference begins early in the crop cycle and often persists through a major part of the growing season. It is caused mainly by weeds that emerge with the crop but also by weeds that emerge after the crop has become established (Hurst and Feltner 1966; Wiese et al. 1964). Kasasian and Seeyave (1969) and Nieto et al. (1959) reported that the first 30 days of the crops' life are the most critical for competition from weeds in maize, beans, tomatoes, and sweet potatoes but that the critical period in yam is much longer.

Uncontrolled annual broad leaves and grasses that constitute the major weed problems in yam plots in the rain-forest zone of Nigeria have reduced yam yield by about 90% (Onochie 1974). This reduction was suggested to be attributable to injury inflicted by weeds during tuberization more than that during canopy formation (Onochie 1974). Work at IITA, Ibadan (1973, 1978), indicated that

the first 16 weeks after planting date are the most critical for competition from weeds with yams, and Onwueme (1975a, b) observed that tuber initiation occurs between 10 and 11 weeks after emergence. This period falls within phase II (6–13 weeks after the plant's emergence) of a four-phase cycle of yam crop growth; it is characterized by foliage development and tuber initiation. Phase I (the period from sprouting to the sixth week after emergence) is characterized almost entirely by the development of a profuse root system and vine elongation; phase III by an increase in tuber bulk; and the final phase, IV, is marked by large-scale senescence of the shoot accompanied possibly by a decrease in tuber dry weight (Sobulo 1972; Njoku et al. 1973).

Although weeds are generally known to reduce tuber yield in yams, very little is known about the basis for this yield reduction. The objective of this investigation, therefore, was to determine the effects of weed interference on the growth and development in white yam and to identify the yield components whose sensitivity to weed interference contributed to the crop-yield reduction.

MATERIALS AND METHODS

The study was carried out in a research farm at the International Institute of Tropical Agriculture. The mean annual rainfall at the experimental site is 1400 mm distributed in two wet seasons — March–July and September–November. Air temperature varies from 20°C to 36°C. The soil is an alfisol (Apomu sandy loam). The environmental conditions favour rapid growth of both yams and weeds.

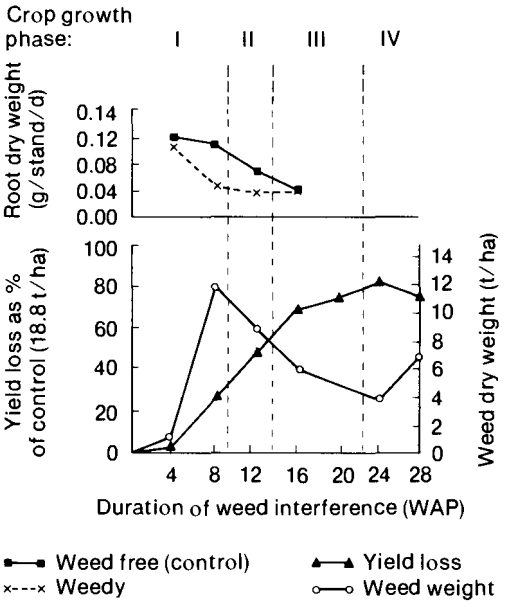

Fig. 1. *Effect of weed interference on root growth and yield of white yam.*

The experiment was set up in a randomized complete block design with three replications. Yam setts (400 g each) were planted at a spacing of 100 × 100 cm on ridges. Each treatment plot was 5 m wide and 10 m long.

The setts for the first and second replicates were presprouted tops, which either were at the two-node stage or were cut back to two nodes, whereas in the third replicate they were nonsprouted tops (thus, time of planting is used here as time of emergence because more than 66% of the total plant population had sprouted at planting time (Onwueme 1978). In any case, all the stands in replicate three had emerged by 4 weeks after planting date. The experiment was set up at the beginning of the rains. The first half of each plot was used for destructive sampling to obtain plant growth and development data. The remaining half was maintained for yam-yield determination. Fertilizer (NPK) was applied at the rate of 30 kg/ha (15:15:15), at 8 weeks after planting.

In one set of treatments, weeds were allowed to grow with the crop for 4, 8, 12, 16, 20, or 24 weeks after yam crop planting, following which the crop was kept weed-free until harvest by repeated hoe weeding. Control plots included plots that were kept either weed-free or weedy until crop harvest.

Three yam stands were randomly sampled for growth and development studies from the portions of the plots set out for destructive sampling. These samplings were taken at 4-week intervals beginning from 4 weeks after emergence and continuing through the 24th week. The data recorded for yams included those on vines, leaf dry-matter accumulation per stand (1 m^2) per day, and fresh tuber relative growth rate (TRGR). We obtained TRGR by finding the Napierian logarithm of the actual weight or area measurement using the method described by Little and Hills (1972). Relative growth rate was used because, where data are subject to unavoidable variation, this figure in graphic representation provides a good indication of the nature of the growth (Evans 1972; Paterson 1949).

We obtained weed biomass data by sampling weeds from a 2-m^2 area in the centre of the two middle ridges in each plot. Biomass data as a function of the ecological activity were considered the best measurement for the weed species population in the experiment (Harper 1960; Truelove 1977). We analyzed data collected on yield compo-

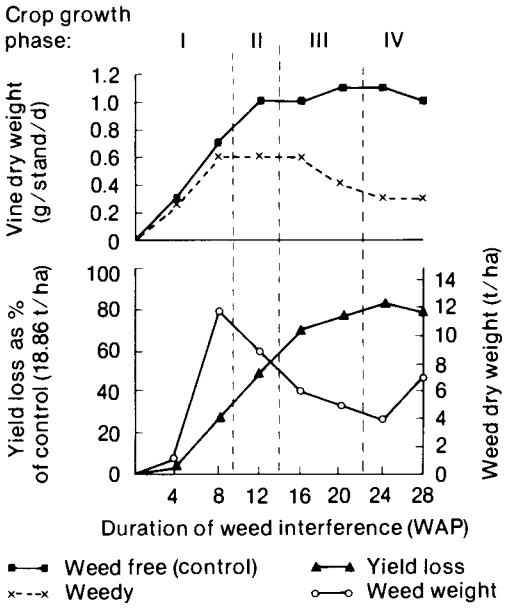

Fig. 2. *Effect of weed interference on vine growth and yield of white yam.*

nents to determine the pattern of growth and development of the crop in relation to the crop yield loss and the accompanying weed dry-matter weight. Correlation analysis was used in determinations of the relationship between yam growth parameters at the intervals in which they showed yield-reducing potential and the percent tuber yield at harvest, as affected by presence or absence of weed interference.

The sample data on the growth of organs were converted to a per-plant basis, whereas the fresh tuber yield at harvest and the weed dry weight at first weeding were converted to a per-hectare basis for data interpretation.

RESULTS AND DISCUSSION

The major weeds at the experimental site were annual broadleaves, grasses, and sedges. The broadleaves included *Acanthosperinum hispidium*, *Ageratum conyzoides*, *Amaranthus spinosus*, *Commelina benghalensis*, and *Euphorbia heterophylla*. The grasses were *Brachiaria deflexa*, *B. lata*, *Digitaria horizontalis*, and the sedges comprised *Cyperus difformis*, *C. nemorallis*, and *Mariscus alternifolium*.

Root, vine, leaf dry-matter accumulation, and the TRGR were affected by uncontrolled weed growth. Reduction in root growth occurred very early in the yam growth cycle (Fig. 1). The patterns of depression in vine, leaf dry-matter accumulation, and TRGR were similar (Fig. 2 and 3). Reduction in leaf dry-matter accumulation occurred earlier than did the reduction in TRGR.

Uncontrolled weed growth significantly reduced dry-matter accumulation in yam roots. This reduction was most pronounced during phase I of the growth period (Fig. 1). The effect of weed interference became pronounced after 4 weeks of weed association with the crop. A close positive correlation between the reduction in root dry-matter accumulation and the reduction in crop yield was observed during the first 8 weeks after planting (Fig. 4).

At this stage of the crop's life, the plant is partially dependent on the mother sett (Onwueme 1978) for its nutrient requirements; therefore, competition for nutrients between weeds and the crop is probably small. The observed reduction in root weight could have been caused by allelopathy.

Phases II and III were critical for vine growth in white yam. Uncontrolled weed growth caused up to 44% reduction in yam vine dry-matter accumulation. Maximum reduction in vine growth occurred at 12 weeks after plant emergence. A correlation existed between the percent loss in vine dry-matter accumulation and the percent reduction in yield at the 16th week (Fig. 5).

There was similarity in the patterns of dry-matter accumulation in the vine and leaves. This is to be expected, as the vine size determines the amount of

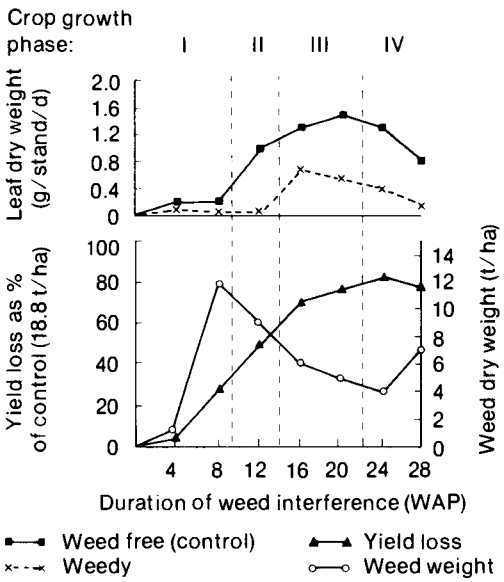

Fig. 3. *Effect of weed interference on leaf growth and yield of white yam.*

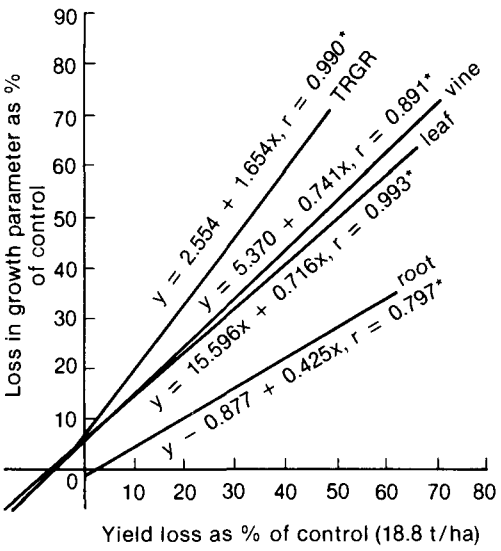

Fig. 4. *Regression of percent loss in growth and development parameters; * = significant at 5% level.*

leaves the plant can support. Although leaf enlargement continues after vine elongation ceases, growth activities in these organs together with photoperiod and other environmental factors contribute to tuber development (Sobulo 1972).

In white yam, phase II constituted the critical period when weed interference reduced dry-matter accumulation in the leaf (Fig. 3). A reduction of 52% in dry-matter accumulation was recorded when the weeds were associated with the crop for the entire season. A positive correlation between the percent loss in leaf dry-matter accumulation and percent crop yield loss was observed during the first 16 weeks (Fig. 4). The effect of weed interference on dry-matter accumulation in leaves was most pronounced during the 8th and 16th weeks. Loss in tuber weight due to weed interference was also very pronounced during this period.

The data suggest that the reduction in the leaf dry-matter accumulation is more important in influencing the final crop yield than is reduction in dry-matter production in the vines or root. This is to be expected because the leaf canopy determines the amount of photosynthate that is manufactured for subsequent transportation to other organs and for storage in the tuber.

The highest value in weed dry weight was observed at 8 weeks after planting date, declining thereafter (Fig. 3). The increase in weed growth possibly interfered with amount of light reaching the lower leaves of the crop, and this interference resulted in less dry-matter production in the growth organs and a reduction in the final yield. Yield reduction caused by shading of lower leaves has been reported for soybean (Johnston et al. 1969; Oliver et al. 1976). If this phenomenon operates in yam, then it is possible that one of the ways through which weeds exert their pressure on the crop is through shading. The contribution of allelopathy to yield reduction in yam cannot be ruled out.

Full season weed interference caused 35% reductions in TRGR in white yam at the 16th week. This period coincides with phase III in the growth cycle (Fig. 5). The closest positive correlation existed between the percent reduction in TRGR and the percent yield loss of white yam at the 12th and 16th weeks after planting date (Fig. 4).

In this investigation, 100% tuber initiation had occurred at the 12th week after planting. Root growth ceased at about the 10th week and was declining at the time of 100% tuber initiation.

Although the greatest depressions in the growth and development parameters and the final yield depressions were manifested at phase III, the damage done by weeds started during the phases I and II and was carried forward to subsequent growth stages.

WEED INTERFERENCE DURATION

The percent yield reduction in white yam steadily increased with weed dry weight up to the 8th week

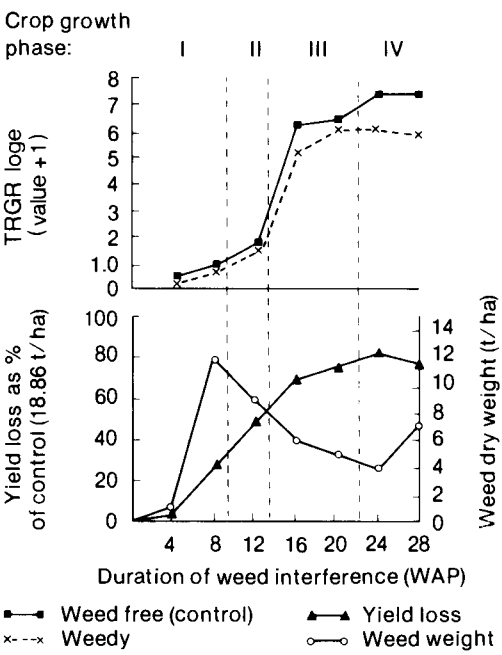

Fig. 5. *Effect of weed interference on tuber relative growth and yield of white yam.*

of weed interference; beyond this point the reduction continued at a decreasing rate (Fig. 1–3, 5). The percent yield reduction for weed interference up to 24 weeks was higher than that for full season interference. This finding possibly reflects moisture losses caused by exposure of topsoil as a result of weed removal late in the growing cycle of the crop, an operation that Kang (Moody and Ezumah 1974) suggested removes the mulching effect of the weeds.

The time that weeds caused serious reductions in tuber yield was synchronized with the intervals during which loss in the growth and development parameters indicated yield-reducing potential.

Based on the highest yield reduction in each phase, the adverse effect of weed interference during growth phase III was 65% more than that caused by weeds during phase I, 36% more than during phase II, and 10% less than during phase IV.

By the 8th week after crop emergence, weed biomass production had picked up in yam plots infested by weeds, and weed species were numerous and varied. By this period, the root growth of the white yam had been greatly depressed. Weed biomass production picked up at the crop vegetative phases I and II when reductions in crop growth parameters indicated yield-reducing potential. The data suggest that the injury inflicted by weeds on the crop early in the season, during vegetative growth, is magnified during the reproductive phase. Reductions in the crop growth and development parameters were closely correlated with percent fresh tuber yield reduction at harvest. Leaving the crop unweeded for any time from 4 weeks to full season produces some losses in crop growth and development and, consequently, in crop yield, but the greatest weed pressure is exerted during the vegetative and tuber-bulking stages.

We emphasize that the results apply to the environment and conditions under which this experiment was performed. Under different situations, with different weed flora, the results may be different.

THE ECONOMICS OF YAM CULTIVATION IN CAMEROON

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Cultivation inputs per hectare of three species of yams (*Dioscorea* spp.) have been carefully recorded and costed. Production costs have been found to be U.S. $1500–$3000/ha to peasant growers for Oshie, white yam (*D. rotundata*), with a cost/tonne of 42 000 francs CFA and 45 mandays/t plus 1 tractor hour. Jakiri yam (*D. dumetorum*) with a cost/t of 19 000 francs and 16.4 mandays/t plus 1 tractor hour. Batibo yellow (*D. cayenensis*) was slightly better than Oshie with 41 000 francs/t and 28 mandays/t plus 1 tractor hour. Despite these high costs, returns were profitable for the three cultivars. Application of mixed fertilizers, especially N and K, resulted in profitable yield increases to Oshie, which also performed well with a groundnut intercrop. But maize intercrop (full stand) caused a yam yield depression of 50%, due to competition for light.

Les coûts de la culture de cultivars de première qualité de trois espèces d'ignames (genre *Dioscorea*), un hectare par espèce, ont été soigneusement calculés et relevés. Les coûts de production d'un fermier s'élèvent entre 1 500 et 3 000 dollars américains par hectare pour *Oshie*; pour une tonne d'ignames blanches, *D. rotundata*, 42 000 francs CFA, 45 j/h et une heure de tracteur; *Jakiri*, *D. dumetorum*, 19 000 francs CFA par tonne, 16,4 j/h et une heure de tracteur; les frais de culture par tonne de *D. cayenensis* sont à peine moins élevés que ceux d'*Oshie*, soit 41 000 francs CFA, 28 j/h plus une heure de tracteur. Malgré des coûts de production élevés, l'opération a été rentable pour chaque cultivar. Les rendements d'*Oshie* ont sensiblement augmenté avec l'apport d'engrais composés, surtout N et K et la production a également été raisonnable en culture associée avec l'arachide. Mais l'association igname-maïs diminue de moitié le rendement de l'igname à cause de la concurrence pour la lumière.

Yams are an important food item in Cameroon but not a staple food in any community. A lively local trade in this commodity exists, ensuring movement from the areas of production (in the savanna and forest zones) to the large towns.

Reliable production figures are not available but an annual tonnage of about 700 000 growing at the rate of 5% may be a realistic estimate. Stoppage of imports from Nigeria has contributed to the expansion in the cultivation of yams.

Eight species (within five sections) of the genus *Dioscorea* are cultivated in Cameroon (Lyonga 1976), but the important economic ones are:

- *D. rotundata*, with 11 cultivars, two of which (Oshie and Mbot) are elites in the highlands and three (Bonakanda, Mbam, Ogoja) of which are elites in the lowlands;
- *D. cayenensis*, with 17 cultivars one of which (Batibo) is an elite in the highlands; and
- *D. dumetorum*, with 13 cultivars, two of which (Jakiri, B45) are elites adapted to both ecological zones.

It is well-known that yam cultivation is expensive compared with that for other tropical root and tuber crops. Coursey (1967b) quotes the following labour inputs per tonne of yam yield from different producing countries: Ghana 55–57 mandays, Nigeria 45, Trinidad 35 plus 20 animal hours, as compared with 2 mandays/t plus 3.2 tractor hours for Irish potatoes in the United Kingdom. He concludes that for yam production to survive, researchers must find ways of cutting production costs by breeding better strains, by improving cultural practices, and by mechanization.

Moody and Ezumah (1974) gave a yam labour input of 190–250 mandays/ha in western Nigeria as against Phillips' (1964) figure of 370–590 for the same country. Gooding (1967) in Barbados established that to break even, a minimum yield of 5 t/ha was required for *D. alata*.

Edwards and Cropper (1967) in the West Indies showed that although labour inputs for yams were higher than those for sweet potatoes, 377–617 and 132–167 mandays/ha, respectively, yams were more profitable than sweet potatoes at low yields of 11.3 and 4.3 t/ha of marketable yield, respectively.

Rankine (1973) found the cultivation of sweet potatoes and yams on a small scale more profitable

Table 1. Fertilizer treatments on Batibo (*D. cayenensis*), 1971.

	Urea (45% N_2)			Bicalcium phosphate (38–40% P_2O_5)			Chloride of potash (60% K_2O)		
	N_0	N_1	N_2	P_0	P_1	P_2	K_0	K_1	K_2
Fertilizer application									
(units/ha)	0	100	200	0	100	200	0	120	240
(kg/ha)	0	220	440	0	250	500	0	200	400
(g/plot)	0	1056	2112	0	1200	2400	0	960	1920
Cost									
(francs CFA/ha)	0	5280	10560	0	7500	15000	0	5000	10000

than on larger farms but the former crop was better, contrary to the findings of Edwards and Cropper (1967).

Vandevenne (1973) reported on the success of partial mechanization of yams in the Ivory Coast in which hand labour could be reduced by 70%. He advocated the necessity for higher yields and a yam with a tuber shape that can be harvested mechanically without injury.

The aim of this study is to confirm some of these findings within Cameroon and thus to lay the basis for ways of reducing input costs so that yam production will be profitable and within reach of peasant growers.

MATERIALS AND METHODS

The four trials in this study were:

- Recording and costing the inputs involved in growing 0.5 ha of Oshie, white yam (*D. rotundata*), at Bambui station (1400 m above sea level) in 1972 and repeated in 1973 and calculating the means for 1 ha;
- Studying the economic returns of mixed NPK fertilizers on three elite cultivars Batibo yellow (*D. cayenensis*), Oshie white (*D. rotundata*), and Kakiri (*D. dumetorum*) in 1973 at Bambui;
- Assessing the economic benefit of intercropping Oshie yam with maize or groundnuts (*Arachis hypogea*); and
- Growing and costing a hectare each of Oshie, Jakiri, and Batibo yams at Bambui in 1978 and 1979 while attempting to reduce certain inputs, like staking and harvesting.

In the first of these trials, 0.5 ha of Oshie cultivar was grown at Bambui highland grasslands as a sole crop in 1972 and 1973, and the inputs were recorded and costed. Standard cultural practices were adopted. Average sett weight was 375 g, spacing was 1 × 1 m, giving 10000 plants/ha. Wooden branched stakes, about 3 m tall each supporting four yams, were used. Mixed fertilizers were 80 units of nitrogen (384 kg/ha of sulfate of ammonia), 50 units of P_2O_5 (278 kg/ha of single superphosphate), and 120 units of K_2O (200 kg/ha of chloride of potash). N and K were halved and applied 50 and 120 days after planting, whereas P was applied at planting. Manesan 80 fungicide was used at the rate of 4.5 kg/ha, applied thrice, against anthracnose disease.

Land preparation was done by tractor (clearing to

Table 2. Fertilizer treatments on Oshie (*D. rotundata*) and Jakiri (*D. dumetorum*), 1972.

	Urea (45% N_2)			Single superphosphate (18% P_2O_5)			Chloride of potash (60% K_2O)		
	N_0	N_1	N_2	P_0	P_1	P_2	K_0	K_1	K_2
Fertilizer application									
(units/ha)	0	80	160	0	40	80	0	120	240
(kg/ha)	0	176	352	0	220	440	0	200	400
(g/plot)	0	840	1680	0	1050	2100	0	960	1920
Cost									
(francs CFA/ha)	0	4224	8448	0	5300	10600	0	5000	10000

ridging). Weed control was manual; hand forks and trowels were used.

Supervision took one-fifth of the time of the headman and watchman for 9 months (the growing period of the crop).

The economic fertilizer was studied at Bambui in 1971 for Batibo and in 1972 for Oshie and Jakiri. A $3 \times 3 \times 3$ factorial design, replicated twice, giving a total of 54 plots, was used. Experimental plot size was 4×12 m (48 m^2) and total plot size was 5×13 m (65 m^2).

Fertilizer was broadcast on the tops and sides of ridges and buried with hand fork. Standard cultural practices were used. Detailed treatments and costs are given (Table 1 and 2).

Intercropping of Oshie yam with maize or groundnuts was a split-plot design with seven main treatments (intercropping and density), and three levels of mixed NPK fertilizers replicated four times and carried out at Bambui in 1973 and 1974. Main plot size was 210 m^2 and subplot size was 30 m^2. Levels of mixed fertilizers were 160 units of N_2, 200 units of P_2O_5, and 240 units of K_2O per hectare (high) and half of these for the low level. N and K were halved, applied equally at planting and 60 days after, and all P was applied at planting.

The two densities of maize used were 50 000 stands (full) and 25 000 stands/ha (half). Those for groundnuts were 200 000 stands (full) and 100 000 stands/ha (half). These crops were planted at the onset of rains (15 March), 3 weeks after the yams were planted.

In 1978 and 1979 the costing exercise on 1 ha each of Oshie, Jakiri, and Batibo was resumed with an attempt to reduce the cost of staking and hand harvesting of tubers. Also, disease control with fungicide was dropped due to the low incidence of anthracnose. Elephant grass stalks (*Pennisetum purpureum*), two to each yam tied at the top in groups of eight (four adjacent stands from two ridges) to form a cone for greater support, were used instead of the more costly wooden stakes.

Farmyard manure at 15 t/ha, costed at 2 CFA/kg, was used on Oshie yam instead of mixed fertilizer

Table 3. Costs of cultivating a hectare of three species of yam as a sole crop.

	1972–73 Oshie		1978–79 Oshie, Batibo, Jakiri		
Input	Mandays (200 F/MD)	Cost 1000 CFA F (% total cost)	Mandays (350 F/MD)	Cost 1000 CFA F (% total cost)	Remarks
Land preparation (tractor up to ridging)	3.3 (20 h)	24.0 (10.5)	2.3 (14 h)	59.0 (17.1)	
Planting material	–		–	150.0 (43)	Jakiri,
(cost)		83.3 (36.6)		300.0 (48)	Oshie, or Batibo
Sett preparation	4		20	7.0 (2.0)	500/day
Mark out and plant	10	2.0 (0.9)	10	3.5 (1.0)	
Fertilizers			–	20.0	
cost	–	26.0 (11.4)	10	3.5 (6.7)	(20:10:10)
mix and apply	9				
Farmyard manure					
cost	–	–	–	30.0	Used in
apply	–	–	30	10.5	1978
Stakes			40	14.0	250/MD
cost (cut)				(5.8)	+
install	56	15.9 (7.0)	3	1.1	cost of
train vines			10	5.0	twine
Weeding (three times)	120	24.0 (10.5)	75	26.3 (7.5)	
Moulding ridges	10	2.0 (0.9)	20	7.0 (2.0)	
Disease control (cost and application)	6	8.0 (3.5)	–	–	
Harvest (hand),	125	25.6 (11.2)	400	140.0 (22.7)	Oshie
weigh, pack			120	42.0 (8.1)	Batibo
			63	22.1 (6.3)	Jakiri
Supervision	50	17.0 (7.5)	50	30.0 (8.6)	1/5 time

Table 4. Summary of cultivation costs for a hectare of three species of yams.

	Oshie		Batibo	Jakiri
	1972–73	1978–79	1978–79	1978–79
Mandays/ha	390	658	358	301
Cost of production/ ha ('000 francs CFA)	227.8	615.4	518.4	348.5
Yields to break even (t/ha)	10.9	10.3	8.6	8.7
Marketable yield (t/ha)	16.6	14.7	12.6	18.3
Mandays/t + tractor hours	22.4+1.3	44.8+1	28.4+1	16.4+1
Cost/t ('000 CFA)	13.7	41.9	41.1	19.0
Profit margin (%)	60.4	42.7	46.5	110.0

in 1978. The harvesting of each cultivar of yams was done and costed separately due to the different tuber shapes and length, which influence the harvest time.

RESULTS

The inputs and costs of growing 1 ha of different species of yams at Bambui station in 1972–73 and 1978–79 are compared in Table 3.

The labour input for Oshie increased by 68.7% from 390 mandays in 1972–73 and the cost of production also stepped up by 170% during the recent costings. This has been principally due to higher wages (from 200 francs in 1973 to 350 francs/manday in 1979), increase in the cost of planting material (from 36.6% of total cost to 43% in Jakiri and 48% in Oshie and Batibo). Also the penetrating nature of Oshie yam tubers made hand harvesting of this cultivar tedious and expensive (400 mandays against 120 for Batibo and 63 for Jakiri).

Although the actual cost of production increased, the proportionate cost of the various inputs did not alter much. There was an actual decrease in the number of mandays spent for staking with elephant grass stalks.

Jakiri had the advantage of lower cost of planting material (half of the others), and harvesting was cheaper due to the globular shape of the tubers, which, quite often, may be harvested by merely pulling the vines.

At a current price of 40 francs CFA/kg of tuber of Jakiri, a yield of 8.7 t/ha of marketable tubers is required to break even; at 60 francs/kg for Batibo and Oshie, 8.6 t/ha and 10.3 t/ha, respectively, are needed to break even. When the price rises to 100 francs/kg, the yields for breaking even reduce to 5.2 and 6.2 t/ha for Batibo and Oshie, respectively.

An actual yield of 17.5 t/ha for Oshie was obtained in 1972–73, and this gave a profit margin of 60.4% allowing for 5% losses. This was equivalent to 22 mandays/t plus 1 tractor hour.

In 1978–79, a marketable yield for Oshie of 14.7 t/ha was obtained, giving a profit margin of 42.7% as against 46.5% for Batibo yielding 12.6 t/ha and 110% for Jakiri with a useful yield of 18.3 t/ha. The mandays/t of tubers were 44.8 plus 1 tractor hour for Oshie, 28.4 plus 1 hour for Batibo, and 16.4 plus 1 hour for Jakiri.

In the fertilizer trials there was a response generally to nitrogen and potash. The costing of each fertilizer input, and the extra returns derived from it gave a better picture of the economic benefit than the usual analysis of variance to determine significance.

Many treatments with no significance over the control were economic with an extra return : cost ratio of more than 2 (which is the point considered profitable) (Table 5).

It should be noted that the lower level of nitrogen, which was not significant over the control, gave a better economic return than did the higher level.

Yam yields were depressed when intercropped especially with maize (50% reduction in the full maize stand). This was expected as there was shading during the growing period, which retarded leaf formation. Yams combined well with groundnuts (Table 6). In two of the treatments with groundnuts, the total yield was profitable. Only one treatment with maize (yams full and maize half) was profitable. Reducing the population density of yam was not profitable. The effects of fertilizers were significant.

DISCUSSION AND CONCLUSIONS

An attempt in 1978 and 1979 to reduce the cost of growing 1 ha each of cultivars of three species of yam in Cameroon was not successful. For Oshie, with a long, penetrating tuber, both labour inputs

Table 5. The economic returns of mixed fertilizer on three species of yam.[a]

Treatment	Cost of fertilizer (+ charges) (1000 francs, CFA)	Value extra yield (return) (1000 francs CFA)	Extra return/cost ratio
		Batibo *(D. cayenensis)*	
N_1	6.2	34.5	5.6
N_2*	11.7	52.5	4.5
$N_2 K_2$	22.1	64.5	2.9
$N_1 P_1 K_1$	19.1	108.0	5.7
		Jakiri *(D. dumetorum)*	
N_1	6.2	47.0	7.6
N_2*	11.7	58.0	5.0
K_1	5.8	28.0	4.8
$N_1 P_1 K_1$	19.1	42.0	2.2
$N_1 P_2 K_2$**	32.1	77.0	2.4
		Oshie *(D. rotundata)*	
N_1*	5.6	28.5	5.1
N_2**	10.0	52.5	5.3
K_1*	6.4	33.0	5.1
K_2*	11.6	55.5	4.8
$N_1 P_1$*	11.8	42.0	3.6
$N_2 P_2$*	21.7	72.0	3.3
$N_1 K_1$	10.8	25.5	2.4
$N_1 K_2$*	16.0	78.0	4.9
$P_1 K_1$	12.6	42.0	3.3
$P_2 K_1$	18.1	48.0	2.7
$N_1 P_1 K_1$	17.0	51.0	3.0
$N_2 P_2 K_2$	32.1	84.0	2.6

[a]* = significance in yield at 5% level of probability; ** = significance in yield at 1%.

Table 6. Effects of intercropping and fertilization on Oshie yam (*D. rotundata*).[a]

Treatment	Yield (t/ha)			Average yield (t/ha)
	F_0	F_1	F_2	
Yams (full stand 10000 plants/ha)	5.0	5.8	5.0	9.4 bc
+ maize (full stand 50000 plants/ha)	3.6	4.5	4.3	
Yams (10000 plants/ha)	6.5	7.5	8.2	11.1 ab
+ maize (half stand 25000 plants/ha)	3.2	4.3	3.6	
Yams (half stand 5000 plants/ha)	4.0	4.0	4.4	7.9 cd
+ maize (half stand, 25000 plants/ha)	3.5	4.2	3.5	
Yams (10000 plants/ha)	7.7	10.9	11.0	11.1 ab
+ groundnuts (full stand, 200000)	1.2	1.2	1.2	
Yams (10000 plants/ha)	9.1	9.6	9.5	10.4 ab
+ groundnuts (half stand, 100000)	1.0	1.0	0.5	
Yams (5000 plants/ha)	4.2	4.8	5.7	5.9 d
+ groundnuts (100000)	1.0	1.0	0.9	
Yams sole (10000 plants/ha)	10.8	13.7	12.1	12.2 a
Mean of all treatments	8.7	10.4	10.1	9.7

[a]The effects of intercropping and fertilizer applications separately were significant; however the effects of both were not significant; the coefficient of variation was 16.94%; average yields followed by the same number are not significantly different as determined by Duncan's multiple range test.

and production costs were increased by 68.7% and 170%, respectively, from the 1972–73 figures.

Despite these increases, yam production of the three cultivars was still economic, with profit margins in 1978–79 of 110% for Jakiri cultivar, 46.5% for Batibo, and 42.7% for Oshie. The marketable yields to break even were 8.7 t/ha for Jakiri, 8.6 t/ha for Batibo, and 10.3 t/ha for Oshie. A labour input of 45 mandays/t of tubers for Oshie is unproductive.

The main drawbacks in yam cultivation, however, seem to be the high labour inputs and the prohibitive costs involved, especially of planting material, in comparison with other root crops, which take less than half the figure for yams. Few peasant growers can afford 300 000-600 000 francs CFA (U.S. $1500–$3000) to establish 1 ha of yams.

The main constraints are the high cost of planting material (about 4 t/ha), a low multiplication ratio (3–4), and high labour costs in staking and harvesting.

The studies of Sadik and Okereke (1975a) to enhance seedling production of white yam and Okigbo and Ibe (1973) to exploit rapid vegetative means of multiplication are commendable and should continue so that the slow supply of planting material can be improved.

Yam breeders must work for a yam with a much higher propagation potential, a yam that uses sunlight more efficiently without supports, a yam resistant to the main fungal and viral diseases, and a yam that is amenable to mechanization, particularly mechanical harvesting, i.e., with a shallow globular tuber. These qualities are additional to those of high yield and high nutritive value.

D. dumetorum is cheaper to produce than other species and is important in Cameroon. Its drawback is that the tuber hardens on exposure to ambient conditions due to cell-wall lignification soon after harvest. Studies to solve this problem are a priority. Unfortunately, Muyuka cultivar, which hardens very slowly, is a very low yielder.

It pays to fertilize yams, especially with nitrogen and potassium. Economic calculations on the profitability of fertilizers give a better picture than does mere determination of statistical significance between treatments.

Intercropping a full stand of Oshie yam with groundnuts or half a stand of maize was economic, especially when fertilizers were used. A full stand of maize with yams is not recommended, as it depresses yam yields (50%).

EFFECT OF TRADITIONAL FOOD PROCESSING METHODS ON THE NUTRITIONAL VALUE OF YAMS IN CAMEROON

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UNITÉ DE NUTRITION DE LA DÉLÉGATION GÉNÉRALE DE LA RECHERCHE SCIENTIFIQUE ET TECHNIQUE, YAOUNDE, CAMEROON

We studied changes of energetic value and chemical composition (moisture, raw fibre, proteins, fat, total carbohydrates, ashes, calcium, phosphorus, iron, thiamine, riboflavin, niacin) of the tubers of *Dioscorea dumetorum*, *D. rotundata*, *D. cayenensis*, and *D. schimperiana* during traditional processing (peeling, boiling, charcoal grilling, frying, and preparation of *fufu*, flour, or "biscuit") and found that cooking in boiling water with the peel and frying are the processes that best preserve the chief nutrients. Grilling and preparation of "biscuit" result in the largest losses.

Les espèces d'ignames, *Dioscorea dumetorum*, *rotundata*, *cayenensis* et *schimperiana* sont analysées avant et après cuisson. Les teneurs en eau, protéines totales, lipides totaux, glucides totaux, fibre brute, cendres, calcium, phosphore, fer, thiamine, riboflavine, niacine, ainsi que la valeur énergétique sont déterminées. Les modes de préparation étudiés sont ceux traditionnellement pratiqués au Cameroun: cuisson à l'eau avant ou après épluchage, *fufu*, cuisson sur braises, farine, friture "biscuit". Les préparations d'igname par cuisson à l'eau avant épluchage et par friture apparaissent comme les plus avantageuses sur le plan nutritionnel. La cuisson sur braises et la préparation du "biscuit" d'igname ont des rendements nutritionnels faibles.

Although there is some information now available on the chemical composition and nutritional value of yams, at least for the principal species, few studies have been carried out on the various ways in which they are consumed, despite the fact that cooking affects the nutritional qualities of foods. Coursey and Aidoo (1966) in Ghana, Oke (1966) in Nigeria, and Leberre et al. (1969) in Cameroon determined vitamin C retention in yams after cooking. Umoh and Bassir (1977) gave the composition in vitamins A, C, B_1, B_2, PP, and B_6 of both raw yams and ready-to-eat *fufu* served with a sauce of leafy greens according to a Nigerian recipe. From the protein and amino-acid contents of cooked yams (*Dioscorea alata*, *D. trifida*, *D. rotundata*, and *D. cayenensis*), Francis et al. (1975) indicated that simple cooking in water affects especially the free amino acids or a small proportion of total amino acids. Splittstoesser (1976), studying *D. alata*, *D. esculenta*, *D. rotundata*, and *D. trifida*, established a relationship between total nitrogen and total amino-acid content of cooked yams. Lastly Ciacco and D'Appolonia (1978) gave the chemical composition of *D. alata* flour and compared it with cassava flour.

Most of the studies dealing with the nutritional value of yams after cooking have been limited to a few nutrients, for one or two African species; furthermore, boiling is often the only means studied. The purpose of our paper is to present an overview of the principal nutritional characteristics of three species of yam that are among those most frequently eaten in Cameroon, *D. dumetorum*, *D. rotundata*, and *D. cayenensis*. A fourth species, *D. schimperiana*, which is rarely covered in the literature, was also studied. Our study focuses on the various ways in which yams are eaten. One of our principal objectives is to make the effect of various processing methods on the chemical composition of yams better known.

MATERIALS AND METHODS

SPECIES

The species we chose were *D. rotundata* and *D. cayenensis*, both very widespread in West Africa; these two, and our third species, *D. dumetorum*, are the main species eaten in Cameroon. One other species was studied, *D. schimperiana*, which is eaten mostly in western Cameroon.

As it would have been difficult for us to establish plantations producing a sufficient quantity of yams of each species, tubers of *D. rotundata*, *D. cayenensis*, and *D. dumetorum* were purchased in Yaounde markets between July 1978 and March 1980. There was no way of determining precisely

Table 1. Cooking methods traditionally used in Cameroon.

	Temperature (°C)	Average time for 1000 g of tuber
Boiling with peel	97	105 min
Boiling without peel	97	30 min
Charcoal grilling	270 (beginning); 200 (end)	40 min
Frying in palm oil	120 (beginning); 175 (end)	26 min
Preparation of flour		
Washing / warm water	97	1 min 30 s
Sun drying	25–30	7 d
Preparation of "biscuit"		
First cooking (with peel)	97	29 min
Sun drying	25–30	7 d
Tray drying (intermittent heating)	40	8 d
Second cooking (dried chips)	97	63 min /100 g

the variety, geographic origin, conditions of cultivation and fertilization, date of harvesting, or storage methods. In order to give the sampling greater homogeneity, we applied each processing method at least three times to one lot of yams bought on 1 day from one seller. The *D. schimperiana* tubers were provided by the Ekona agricultural station. These were harvested during October 1978 and October 1979. Two varieties were studied: *D. schimperiana* ex. Dschang and *D. schimperiana* ex. Bui.

Immediately after either the harvesting of the tubers or their purchase in the market, they were conveyed to the laboratory where they were kept in the same conditions, at ambient temperatures, for a maximum of 2 weeks.

SAMPLING

Three identical groups of tubers were made up from one lot, each tuber being cut lengthwise. The first was intended for analyses on the bulk product as bought, the second, for analyses on the raw product, and the third for undergoing the various processes. Each method was repeated at least three times. It was not possible to analyze *D. schimperiana* as a bulk product.

PROCESSES

We applied the traditional methods in use in the various regions of Cameroon. They vary from one species to the other. Idowu (1976) and Grimaldi and Bikia (1977) have inventoried them (Fig. 1, Table 1).

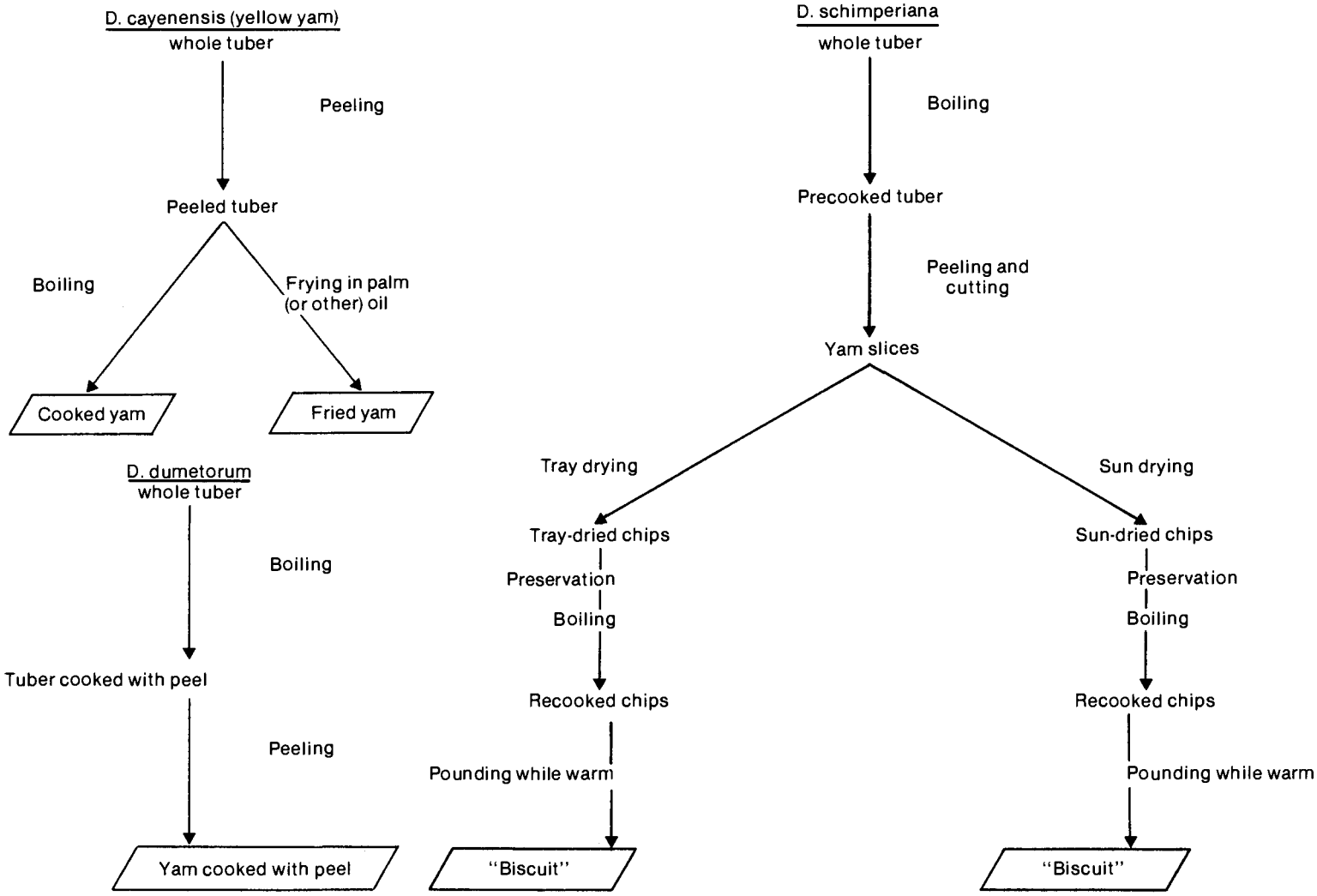
CHEMICAL COMPOSITION

We determined the chemical composition as follows:

- Water, thiamine, riboflavin, and niacin content of raw or cooked products, immediately after processing; the products were crushed and homogenized, and five samples were taken for each type of analysis;
- Water, total nitrogen, fats, insoluble formic, ashes, calcium, phosphorus, and iron content of the same products after they had been vacuum-dried (45°C), crushed, stored in a freezer until the day before sampling. Two samples were taken from the dried products.

We determined water content by oven drying at 102–105°C to constant weight; total nitrogen by the Kjeldahl method (PROLABO notice E-1732 02; coefficient of conversion of total nitrogen into protids = 6.25); total fats by extraction with petroleum ether in Soxlet for 10 h, without preliminary hydrolysis; and total carbohydrates by calculating the difference between dried extract and the sum of the protids, fats, and ashes. To calculate energy value, we used Merrill and Watt (1955) coefficients, adopted by FAO (1970): 2.78 for protids, 8.37 for fats, and 4.03 for carbohydrates. Fibre was considered to be the insoluble formic determined by the Guillemet and Jacquot (1943) method. We determined total ash by incineration in a muffle furnace at 550°C for 1 night; nitrohydrochloric solutions of ashes were used in flame photometry for calcium determination and in colorimetry for phosphorus (Stuffins 1967) and iron. We undertook microbiologic determinations of the B vitamins according to methods of:

- Diebel et al. (1957) for thiamine, using *L. viridescens* (ATCC 12706);
- Snell and Strong (1939) for riboflavin, using *L. casei* (ATCC 7469); and
- Snell and Wright (1941) for niacin, using *L. plantarum* (ATCC 8014).


D. cayenensis (yellow yam)
whole tuber
Peeling
Peeled tuber
Boiling
Frying in palm (or other) oil
Cooked yam
Fried yam
D. dumetorum
whole tuber
Boiling
Tuber cooked with peel
Peeling
Yam cooked with peel
D. schimperiana
whole tuber
Boiling
Precooked tuber
Peeling and cutting
Yam slices
Tray drying
Sun drying
Tray-dried chips
Preservation
Boiling
Recooked chips
Pounding while warm
"Biscuit"
Sun-dried chips
Preservation
Boiling
Recooked chips
Pounding while warm
"Biscuit"

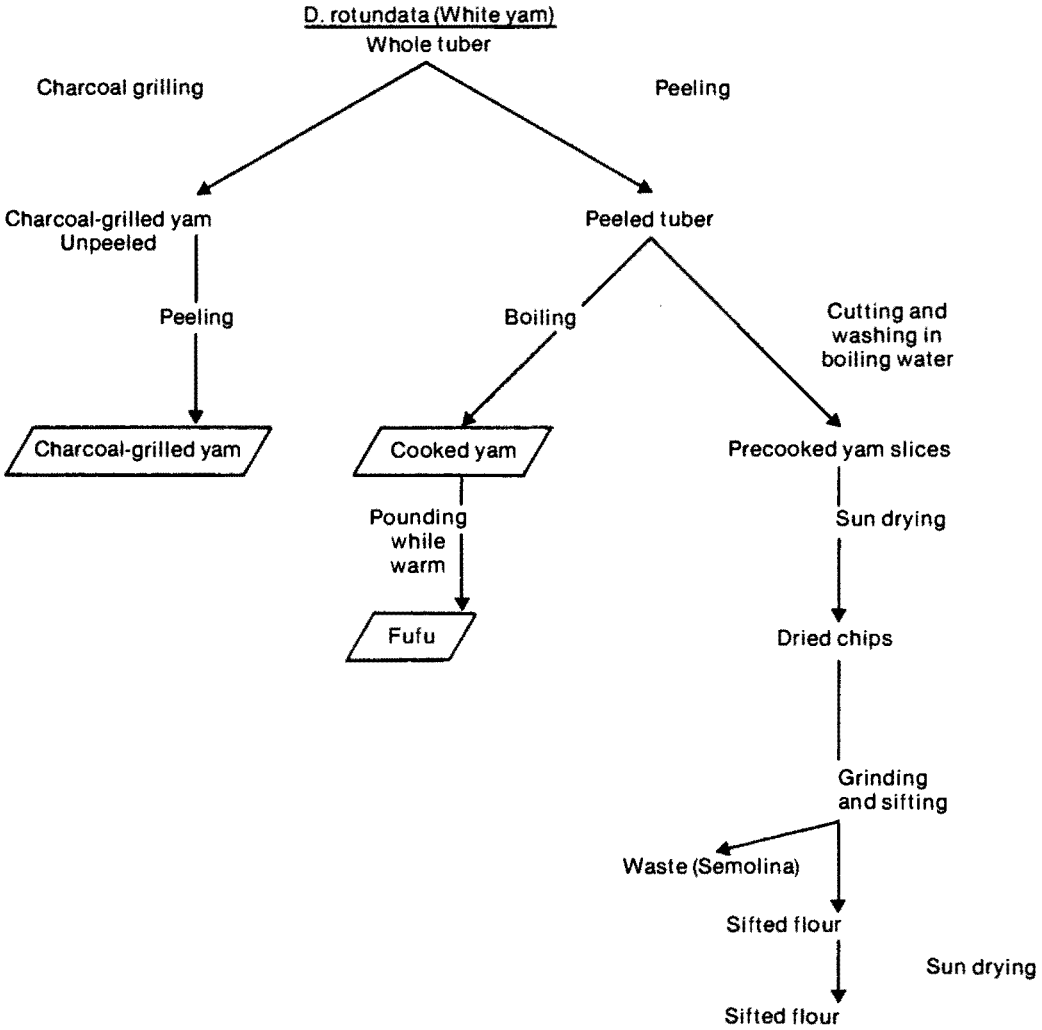


Fig. 1. *Traditional processing of yams (ready-to-eat products are in boxes).*

Table 2. Chemical composition of yams and derivatives (per 100 g edible portion).

	Sample no.	Moisture (%)	Calories	Proteins (g)	Fat (g)	Carbohydrates (g)	Fibre (g)	Ash (mg)	Ca (mg)	P (mg)	Fe (mg)	Thiamine (μg)	Riboflavin (μg)	Niacin (mg)	Ascorbic acid (mg)[a]
D. dumetorum															
Raw yam	3	73.5	101	2.5	0.11	23.2	1.28	0.78	32	49	0.78	127	64	0.48	
Boiled, unpeeled yam	4	74.8	97	2.2	0.10	22.2	1.37	0.73	43	46	1.0	108	55	0.36	
D. rotundata															
Raw yam	14	70.3	115	1.3	0.05	27.5	0.64	0.81	26	41	0.66	85	30	0.42	9.4
Boiled, peeled yam	6	74.2	100	1.1	0.03	24.0	0.81	0.61	16	30	0.85	69	20	0.32	5.7–6.2
Fufu	4	76.3	92	1.1	0.02	22.0	0.58	0.59	12	27	0.87	75	23	0.25	
Charcoal-grilled yam	3	65.4	133	0.8	0.04	33.0	0.61	0.80	54	43	0.90	73	20	0.29	7.8–8.2
Sifted flour (mortar)	3	10.6	347	4.5	0.33	82.3	1.4	2.3	99	102	4.8	116	36	1.3	
Sifted flour (grinder)	6	11.8	342	3.6	0.16	82.1	1.5	2.3	100	117	5.5	237	71	0.98	
D. cayenensis															
Raw yam	8	71.0	112	1.2	0.07	26.8	0.70	0.90	28	44	0.38	86	17	0.36	
Boiled, peeled yam	3	73.0	105	1.0	0.11	25.1	0.57	0.80	19	38	0.35	55	16	0.27	
Yam fried in palm oil	4	36.2	295	1.8	10.7	49.9	1.6	1.4	73	51	3.0	164	24	0.53	
D. schimperiana ex. Dschang															
Raw yam	2	78.2	83	1.8	0.04	19.2	0.85	0.76	10	26	0.46	56	29	0.26	
Boiled, unpeeled yam	2	80.4	74	1.4	0.04	17.4	0.71	0.76	15	37	1.3	41	27	0.22	
"Biscuit" after sun drying	1	71.6	111	1.8	0.29	25.6	1.44	0.75	29	43	7.7	22	7.3	0.14	
D. schimperiana ex. Bui															
Raw yam	1	84.5	56	1.5	0.05	12.8	1.2	1.1	32	37	1.0	34	11	0.26	
Boiled, unpeeled yam	1	84.3	58	1.4	0.04	13.4	1.3	0.83	33	34	1.5	27	9.6	0.17	
"Biscuit" after tray drying	1	79.6	78	1.9	0.11	17.9	1.9	0.54	53	32	5.5	7.8	4.9	0.10	

[a]From Coursey and Aidoo (1966).

STATISTICAL METHODS

Results both before and after the tubers were cooked were compared on the basis of the Student's *t* test for two averages and for pairs of variables (Snedecor and Cochran 1957).

RESULTS

Table 2 shows average nutrient contents of the edible portion of the samples analyzed before and after cooking. Table 3 indicates the variation observed in the chemical composition during the various processing methods.

On the basis of the reduction in the amount of nutrients in relation to dry matter or to dry matter minus its fat (in the case of fried yam), the preparation of "biscuit" appears to be the most detrimental process. *D. schimperiana* is first boiled, unpeeled, then peeled, and dried. It is then boiled again and pounded while warm. Nutrient losses range from 4 to 14% for proteins; 33 to 63% for mineral elements; 71 to 83% for thiamine, 65 to 81% for riboflavin (the sun drying in "biscuit" preparation is most harmful), and 59 to 71% for niacin. Calcium, iron, and fibre alone suffer no reduction during this process.

Next come the preparation of *fufu* and the boiling-after-peeling method. With these two methods, nutrient losses are respectively 13 and 14% for minerals, calcium being most affected; 14 and 13% for riboflavin; 25 and 23% for thiamine, and 27 and 26% for niacin.

It is rather surprising to observe that, in the boiling-after-peeling method, niacin losses of *D. rotundata* and *D. cayenensis* compare with those of thiamine. Such losses would be expected for thiamine, which is thermolabile but niacin has little sensitivity to heat. However, this finding agrees with Paul and Southgate (1978) who evaluated average losses of thiamine, riboflavin, and niacin during boiling at 25, 30, and 30%, respectively. One explanation might be that the solubility of niacin is as considerable as that of thiamine.

Table 3. Effect of traditional processing methods on chemical composition of yams.[a]

	Dry matter	Proteins	Carbohydrates	Fibre	Ash	Ca	P	Fe	Thiamine	Riboflavin	Niacin
Raw yam (edible portion)	100	100	100	100	100	100	100	100	100	100	100
Boiled, unpeeled tubers											
D. dumetorum (yellow fleshed)	−4	−7	0	+4	+1	+49**	+3	+22	−17**	−4	−23**
D. schimperiana ex. Dschang	−1	+1	0	−10	−2	+32**	−4	+156**	−23**	+4	−26**
D. schimperiana ex. Bui	+1	−6	+3	0	−27**	+2	−10**	+39**	−21**	−11	−36**
Boiled and peeled tubers											
D. rotundata	−4	+1	0	−1	−14**	−36**	−16**	+28	−23**	−13*	−26**
D. cayenensis	0	−1	0	+1	−8	−7	−13	+4	−22**	−14*	−21**
Fufu											
D. rotundata	−9**	0	0	−6	−13**	−20	−19**	+51	−25**	−14*	−27**
Charcoal-grilled tubers											
D. rotundata	+12*	+4	0	−21	+2	+7	+15	+23	−13*	−8	−4
Flour											
D. rotundata											
Washing in boiling water	−4	+3	0	+4	−5	−5	−4	+21	−11	−2	−7
Sifted flour (mortar)	+168**	0	0	−8	+3	−5	0	+308**	−24**	−37*	−10
Sifted flour (grinder)	+167**	+2	0	−31	−4	−3	−11	+225**	−21*	−36*	−9
Frying in palm oil[b]											
D. cayenensis	+94*	−4	0	−1	+8	0	−2	+71**	−2	+4	−3
Biscuit											
D. schimperiana ex. Dschang											
Sun-dried chips	+328**	+2	0	−2	−4	+37**	−4	+337**	−42**	−73**	−26**
"Biscuit"	+43**	−14*	+2	+9	−33**	+70**	−22**	+981**	−71**	−81**	−59**
D. schimperiana ex. Bui											
Tray-dried chips	+421**	+3	−1	−	+13	+7*	−17**	+280**	−59**	−40*	−39**
"Biscuit"	+32*	−4	+6	+16*	−63**	+27**	−34**	+298**	−83**	−65**	−71**

[a]Significance: * = $P<0.05$; ** = $P<0.01$.
[b]Calculations were made on dry matter with fats removed.

Table 4. Losses in peeling.

	D. rotundata (n=3)			*D. cayenensis* (n=3)			*D. dumetorum* (n=2)		
	Bulk	Peeled	% change after peeling	Bulk	Peeled	% change after peeling	Bulk	Peeled	% change after peeling
Dry matter (g)	27.7	29.3	6	26.6	24.0	−10	21.9	25.3	15
Calories	386.3	388	1	385	387	1	376	380	1
Protein (g)	3.46	3.72	8	4.8	4.3	−10	10.62	10.13	−5
Fats (g)	0.17	0.12	−29	0.51	0.48	−6	0.48	0.42	−13
Carbohydrates (g)	93.1	93.4	0	91.1	92.1	1	85.3	86.5	1
Fibre (g)	3.8	2.3	−39	3.2	1.8	−44	8.1	5.4	−33
Ash (g)	3.3	2.8	−15	3.2	3.1	−3	3.6	2.9	−19
Ca (mg)	115	123	6	78	53	−32	214	110	−49
P (mg)	150	136	−9	153	137	−10	227	198	−15
Fe (mg)	12	1.6	−87	6.5	0.7	−89	8.3	3.8	−54
Thiamine (μg)	542	357	4	206	247	20	705	558	−21
Riboflavin (μg)	116	109	−6	43	44	1	310	291	−6
Niacin (mg)	1.3	1.2	−8	1.3	1.2	−7	2.2	2.1	−5

Table 5. Percentage of tuber constituting peel.

	Observations	Average (% of tuber as purchased)	Extreme values (% of tuber as purchased)
Raw yams			
D. rotundata	27	23	16-39
D. cayenensis	17	25	13-34
D. dumetorum	3	26	21-30
D. schimperiana	2	25	21-30
Boiled, unpeeled tubers			
D. dumetorum	3	14	10-21
D. schimperiana	5		
ex. Dschang	3	13	10-16
ex. Bui	2	17	17-17
Charcoal-grilled tubers			
D. rotundata	3	33	31-35

Cooking in fact involves dissolving through heat with continuous agitation. Furthermore, the niacin concentration in the boiling medium is, on average, only 0.50 mg/100 ml of water, whereas niacin is soluble in proportions of 1.2–1.6 g/100 ml of water, and thiamine, 100 g/100 ml (Adrian 1959).

The preparation of flour affects mainly thiamine and riboflavin, average losses being 22% for the former and 37% for the latter. This process causes little change in the mineral content. The differences observed between flour pounded in a wooden mortar and that ground in an electric mixer are not statistically significant.

Boiling of unpeeled *D. dumetorum*, although a relatively lengthy process, has little effect on nutritional values. The most important losses occur in thiamine (-17%) and niacin (-23%). The difference, with thiamine having the edge, may be explained by the diffusion of the soluble vitamins from the peel to the flesh of the tuber during cooking. We were able to verify that the bulk tuber is richer in thiamine than in niacin in comparison with the peeled tuber (Table 4). Prolonged boiling also entails fairly important protein losses.

Boiling of unpeeled *D. schimperiana* entails fairly considerable losses probably because the tuber had been cut lengthwise then fragmented several times because of its length, the process leaving the tuber partly peeled. Again, thiamine and niacin were most affected, with respective average losses of 21–23% and 26–36%, depending on the varieties. Protein losses varied.

The processes that appear most advantageous are charcoal grilling and frying in palm oil. The first is detrimental only to thiamine (-13%); the fibre content is also reduced (-21%), but this change is not significant. No significant loss is observed during the frying-in-palm-oil method.

Nutrient losses also depend on the amount of peelings. It is clear then that boiling with peel gives the best nutritional balance; peeling after boiling makes available a larger part of the edible portion (Table 5). Results obtained from boiled, unpeeled *D. dumetorum* indicate that the only sizable losses occur in iron (-50%), thiamine (-38%), and niacin (-31%).

Boiling of peeled *D. cayenensis* gives a nutritional balance inferior to that obtained with frying, especially where vitamins B_1, B_2, and PP are concerned.

Pounding for *fufu* has little effect on the nutritional balance obtained after the peeled yam has been boiled. Methods most detrimental to the nutritional balance in comparison with the whole tuber are charcoal grilling and the "biscuit" method. Although the former maintains favourably the nutrients in the edible portion of the grilled tuber, a large amount of matter is charred in the process. On average, 54% of the dry matter is lost; 62% of the mineral elements; more than 90% of the iron; and 60% of the thiamine, riboflavin, and niacin. In view of the insufficient quantity of *D. schimperiana* at our disposal, it was not possible for us to determine the nutritional contents for the entire tuber after the preparation of "biscuit," but the nutritional value of the product obtained from 1 kg of bulk yam indicates that the balance will probably be unsatisfactory (Table 6), as this process is particularly harmful.

Lastly, let us note that the nutritional balance of yam flour is also relatively unsatisfactory, partly because of the waste matter remaining after the flour is sifted — a waste that represents more than a quarter of the energy value of the flour (Table 7).

It appears that boiling unpeeled tubers and frying tubers in palm oil are the most advantageous

Table 6. Nutritional balance of derivatives of a kilogram of yam as purchased.[a]

	Dry matter (g)	Calo-ries	Protein (g)	Fat (g)	Carbohy-drates (g)	Fibre (g)	Ash (g)	Ca (mg)	P (mg)	Fe (mg)	Thia-mine (mg)	Ribo-flavin (mg)	Niacin (mg)
Boiled, unpeeled													
D. dumetorum	207	790	19.1	0.9	181	12.1	6.0	329	407	10.4	1.0	0.54	3.2
D. schimperiana ex. Dschang	171	649	14.2	0.3	151	6.4	5.8	105	195	9.0	0.34	0.23	1.9
D. schimperiana ex. Bui	111	413	10.0	0.3	95	8.9	5.9	231	240	10.4	0.19	0.07	1.2
Boiled, peeled													
D. rotundata	209	811	9.1	0.2	195	4.5	5.1	118	281	5.1	0.54	0.19	2.3
D. cayenensis	215	827	8.0	0.5	200	5.1	5.7	195	254	2.8	0.56	0.10	1.7
Fufu													
D. rotundata	195	756	8.5	0.2	181	4.0	4.7	138	256	5.7	0.43	0.17	2.1
Charcoal-grilled													
D. rotundata	120	499	6.0	0.2	119	1.7	3.5	126	204	2.9	0.32	0.12	1.8
Sifted flour													
D. rotundata (mortar ground)	167	646	7.4	0.2	155	3.4	4.8	140	234	15.8	0.37	0.10	2.2
D. rotundata (electrically ground)	164	634	7.4	0.2	152	2.5	4.4	141	204	13.3	0.37	0.10	2.2
Fried in palm oil													
D. cayenensis	252	1359	8.6	87.4	150	6.3	6.7	206	299	19.2	0.59	0.13	2.6
"Biscuit"													
D. schimperiana													
ex. Dschang (sun dried)	112	434	8.0	1.0	100	5.9	2.8	89	103	25.3	0.09	0.03	0.57
ex. Bui (tray dried)	88	335	8.0	0.5	77	8.2	2.3	228	139	23.6	0.03	0.02	0.43

[a]Bulk yams as purchased, i.e., before being peeled.

Table 7. Chemical composition of waste from sifting flour from yam.

	Weight (g)	Dry matter (g)	Calories	Protein (g)	Fats (g)	Carbohydrates (g)	Fibre (g)	Ash (g)	Ca (mg)	P (mg)	Fe (mg)	Thiamine (μg)	Riboflavin (μg)	Niacin (mg)
Mortar pounded														
Waste/100 g dry matter		78.9	387	4.9	0.31	91.9	2.6	2.9	114	158	3.8	300	69	1.3
Waste/kg yam as purchased	61	48.1	186	2.4	0.15	44.2	1.3	1.4	55	76	1.8	144	33	0.62
Electrically ground														
Waste/100 g dry matter		79.8	386	4.7	0.13	92.4	3.4	2.3	73	129	4.8	258	68	1.4
Waste/kg yam as purchased	56	44.7	173	2.1	0.06	41.3	1.5	1.2	32	58	2.13	115	30	0.64

methods as far as nutritional value is concerned. Charcoal grilling and "biscuit" should be condemned. With *D. schimperiana* this solution presents a problem. This edible yam is not widespread; it has a coarse texture and poor culinary qualities. Yet it is much prized by the Bamileke of Western Cameroon, who eat it as "biscuit." This method improves the organoleptic qualities of this yam and is a means of preserving it for the off-season or for use in times of shortages. A process eliminating the disadvantages of the double cooking would improve the use of this yam. To this end, processing into flour might be advisable. Because flour is not always appreciated by the African consumer, preparing a puree by pounding the yam after it has been peeled, boiled, and cubed might be a more acceptable method, but this would then make preservation impossible.

Charcoal grilling by itself entails only a slight nutrient loss, but it does entail a great loss in dry matter through charring. Reducing this loss through appropriate processes would therefore be worthwhile.

Flour has the advantage of being a product that keeps well and is easy to market even at great distances. The traditional method of preparing yam flour gives a relatively poor nutritional result. Various home or industrial methods have been described (Afable 1971; El dash et al. 1978; Gamboa 1944; Jarmai and Montford 1968; Martin and Ruberte 1975; Misawa and Matsubara 1965). Taking into account the effect of the various processes on the yam's nutritional value, we believe that processes entailing cooking before peeling are the most advantageous. They also eliminate the discoloration that occurs in certain varieties of yams after peeling. Traditional sun drying of yams entails serious losses of B vitamins. Appropriate technologic applications (for example, solar dryers) might reduce the length of time required. Lastly, the use of a recycling grinder would make it possible both to obtain a sufficiently fine flour and to reduce the waste matter from the sifting process. The wastes might in fact be used in animal feedstuffs.

From a nutritional point of view, yams appear to be one of the most valuable tropical tubers. On the basis of an average daily consumption of 300 g of bulk yam per person (statistics on yam production in Cameroon, Ministère de l'agriculture 1978), a figure that indicates a relatively low consumption in comparison with plantains or cassava and with reference to the joint recommendations of FAO experts concerning people's nutritional requirements (OMS 1973; Passmore et al. 1974), raw yams may meet the adult Cameroonian's requirements as follows: energy, 10%; proteins, 9%;

calcium, 16%; phosphorus, 25%; iron. 9%; and thiamine, 22%. Cooking affects these figures. Vitamins are the nutrients most affected; after cooking, yams provide only 14% of an adult's thiamine requirements.

It appears necessary to determine precisely the nature and proportions of the various chemical forms, free or conjugated, in which the B vitamins — in particular B_1, B_2, and PP — occur in yams. It is probable that they are found in the free state. We were in fact able to extract 96% of the total thiamine content, 95% of the riboflavin, and 97% of the niacin from *D. rotundata* by simple agitation in cold water. But these data should be researched in greater depth with stricter methods that would improve our understanding of the ways in which these vitamins are lost.

It is also necessary to determine the effects of processing upon the availability of minerals in yams; our knowledge in this area is still poor. And yet both cooking and other methods such as fermentation affect certain chemical complexes in minerals such as phytin (Joseph 1973; Oke 1966).

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This paper was originally French; with the author's permission, it was translated into English for inclusion in these proceedings.

COCOYAMS

STRATEGIES FOR PROGRESS IN COCOYAM RESEARCH

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Although natural flowering and seed setting are rare in the cocoyams — *Colocasia* and *Xanthosoma* — mutual interactions of polyploidization, occasional somatic mutations, and introductions to new and contrasting environments and growing conditions, followed by selection over several centuries in cultivation, have produced an impressive array of variability within the two species. This variability, which has accumulated on account of the vegetative means of propagating the species, if exploited, can benefit the entire African continent through systematic collection, evaluation, and distribution of elite cultivars. Variability can further be increased and superior varieties developed when flowering, seed setting, and methods of hybridization and breeding procedures are worked out. Suggestions are given as to how these can be achieved.

La formation naturelle d'inflorescences et de graines est rare chez les taros *Colocasia* et *Xanthosoma*, l'interaction de la polyploïdation, des mutations somatiques accidentelles, leur introduction dans des nouveaux milieux où les façons culturales sont différentes, facteurs associés à la sélection pratiquée au cours des siècles, ont augmenté la variabilité de ces espèces de façon impressionnante. Le continent africain tout entier pourrait profiter de l'exploitation immédiate de ces caractéristiques dues à la multiplication par voie végétative de ces espèces, et on pourrait procéder à la constitution de collections systématiques, à l'évaluation et la distribution de cultivars supérieurs. La variabilité pourrait être accrue et des variétés encore plus parfaites obtenues par des méthodes de reproduction et d'hybridation au moment de la floraison et de la nouaison. On suggère des moyens pour y parvenir.

The cocoyams — *Colocasia* and *Xanthosoma* — are the two most important genera of the family Araceae. The other three genera *Alocasia*, *Amorphophallus*, and *Cyrtosperma* are important as food plants only in the pacific basin.

Originating in Southeast Asia, probably in India or Malaysia, where wild forms are still found, *Colocasia* spread throughout India and the pacific basin (including New Zealand and Hawaii) in prehistoric times (Burkhill 1938; Porteres 1960). It reached Egypt through the Middle East in 100 AD and later spread westward along the Mediterranean and across Africa to the Guinea Coast (West Africa). By 1500 it was already in cultivation in Gambia and Sao Thome. Madagascar, which is culturally linked with Indonesia, is believed to be another route by which the cultivation of *Colocasia* diffused through Africa. From West Africa, it reached tropical America in the early 1500s, and by 1800 it had spread from the Caribbean to Brazil and, recently, to the south coast of the USA. The cultivation of *Colocasia* is therefore worldwide — throughout the tropics to the borders of the temperate regions.

Xanthosoma originated in tropical America and was in cultivation in pre-Colombian times. It occurs from Mexico to Brazil, but its cultivation is concentrated in the Caribbean. It was introduced during the 1840s or probably earlier by West Indian missionaries into West Africa (Wright 1930b), from where it spread to other parts of Africa. It is also cultivated in Oceania and Southeast Asia. Its cultivation, like that of *Colocasia*, is pantropic, but because of its superiority over the latter, in yield, taste, adaptability, and resistance to pests and diseases, *Xanthosoma* is rapidly displacing *Colocasia* in West Africa and probably in other parts of the world also.

CLASSIFICATION AND VARIABILITY

There has been considerable controversy about the taxonomy of *Colocasia*. The taro, eddoe, dasheen curcas (Kolkas), or "old" cocoyam, are all forms of a plant originally described as *Arum esculentum* but now referred to as *C. esculenta* or *C. antiquorum*. The name having priority and, therefore, validity, however, is *C. esculenta*. Taro is the paddy form and the others are dryland forms.

Classic Linnean taxonomic concepts are not always rigidly applicable to plants that have been in

cultivation for a long time and especially where vegetative propagation and clonal selection have been practiced over several centuries, giving rise to continuous variation of forms. Hill (1939), therefore, treated the taros as a polymorphic species, *C. esculenta*. (*C. esculenta* is taro, and *C. esculenta* cv. globurifera is dasheen.) This classification is shared by several workers.

There are hundreds of cultivars of *C. esculenta* differing in corm size, shape, texture, colour, starch, properties, acridity, storage characteristics, number of secondary corms, and uses. Cultivars also differ in fertilizer and irrigation requirements, pest and disease resistance.

These variations have probably arisen through somatic mutations, genetic recombinations brought about as a result of chance seed setting, chromosomal aberrations and polyploidization (both euploidy and aneuploidy). Reported chromosome numbers (2n) are: 14, 22, 26, 28, 38, and 42; 2n = 28 predominantly occurs in India, Japan, and Polynesia and 2n = 42, in India, New Zealand, and the Philippines (Yen and Wheeler 1968).

Thus, because of the predominantly vegetative mode of propagation of *Colocasia* and its long history as a cultivated crop, it has been possible to select and preserve over the ages types of variation found useful to humans. The accumulation of these different types has made it possible for suitable cultivars to be found in different areas and in various growing conditions of soil, water, altitude, temperature, management, planting practices, etc.

This large store of variation is immediately available for utilization in its raw state and in all future combinations and recombinations, if conditions for flowering, hybridization, seed setting, and raising of seedlings are discovered.

Like *Colocasia*, variability within *Xanthosoma* is fairly large. The genus includes crops popularly known as Yautia, Tannia, Macabo, Mafaffa, or new cocoyam. Agriculturalists usually refer to the edible corm-producing representatives of *Xanthosoma* simply as *X. sagittifolium*. However, a number of species have been identified based mainly on vegetative characteristics (Haudricourt 1941) from the multiplicity of cultivated forms. These include *X. sagittifolium; X. jacquini; X. carcacu; X. mafaffa* (three cultivars); *X. atrovirens* (five cultivars); *X. beloplylum* (four cultivars); and *X. brasiliense*.

Detailed descriptions of these are available in the literature (Gooding and Campbell 1961a; Karikari 1971). As was indicated for *Colocasia*, it is doubtful whether all these taxa can stand any rigorous Linnean taxonomic classification. Variability in *Xanthosoma*, however, appears less than in *Colocasia*, and the literature on the crop is also comparatively sparse. Chromosome numbers are not available, although for *X. sagittifolium*, 2n = 26 has been reported, suggesting that it is a diploid (Wilson 1974). However, variability parallel to that found in *Colocasia* regarding maturity period, corm texture, taste, colour, size, utilization of leaves, etc. also occurs in the *Xanthosoma* species and cultivars that have been identified.

NATIONAL RESEARCH PROGRAMS

Of the root crops cultivated in Africa, cocoyams have received the least research attention. Research on cocoyams, which started as far back as the early 1930s, has not been sustained; more attention has been given to yams and cassava. For example, in Ghana in 1925 there were attempts to find the causal organism and control measures for a disease described as root rot (Wright 1930a). Posnette (1945) of cocoa swollen-shoot fame continued the investigation and came out with far-reaching recommendations. So far as I am aware that is where the matter has rested. Posnette (1945) also made several introductions including *X. violaceum* and attempted induction of flowering, hand pollinations, and raising of seedlings in a bid to produce disease-free material for distribution. This work was not pursued. The example of Ghana is parallel to that in several African countries. The priority rating of crops was and is still cash or export crops (cocoa, oil palm, rubber, etc.), food grains (cereals and legumes), and root crops under which cocoyams have had the lowest priority.

STRATEGY FOR PROGRESS

Any strategy must be well-planned and the various steps involved, well-coordinated if good progress is to be made. The planning should be done from an institution like IITA or the National Root Crops Research Institute, Umudike, which should coordinate the work of cooperating institutions throughout Africa. A two-phased program is suggested:

- Phase I (short-term) would be an interim phase during which identification, evaluation, and rapid distribution of elite cultivars among those already available should be made;
- Phase II (long-term) would start as soon as possible but not until all accessions have been properly identified, classified, and screened. Eventually, programs under this phase would supersede those in phase I and would be the

main programs to be pursued. Research at this stage would be multidisciplinary with physiology, pathology, and entomology as major disciplines providing basic information for breeding and agronomy for the long-term improvement of cultivars, their cultivation, and utilization.

PHASE I

The circumstances surrounding the earlier introductions could not have ensured that the most suitable or appropriate cultivars have always reached desired locations. If they have, it has been merely fortuitous. Poor flowering and seed setting have meant that clonal selection could only be carried on within the limited material available, i.e., the original introductions and perhaps new types produced by the very rare occurrences of somatic mutations and chance seed setting. At best, selection would have been short-lived because variability would have been quickly exhausted. Our "best" cultivars of today, therefore, may have been much different if the earlier introduction had been of a different mixture.

There is, therefore, the need for a systematic collection program aimed at obtaining both wild and cultivated material from all parts of the world where cocoyams are important and especially where collections already exist. For *Colocasia* these are Hawaii, the Pacific basin, India, and New Zealand; for *Xanthosoma*, the Caribbean islands and other parts of Latin America. There is no comprehensive collection of *Xanthosoma* anywhere, and such a collection exercise is long overdue. The ISTRC — AB should, with the appropriate support, i.e., funds, equipment, etc., assign the job of collection and maintenance to an African institution or institutions, such as IITA, that have the capacity and the expertise.

Problems of collection and maintenance are many, and the few attempts in the past had to be abandoned for want of continuing funds. The problems include:

- Bulky and highly perishable planting materials that are expensive to store and transport;
- Maintenance of living collections by continuous planting, which is laborious and expensive and leads to accumulation of pests and diseases, particularly viruses, in the planting material, resulting in complete deterioration and ultimate loss of the material; and
- Lack of effective means of disinfection or disinfestation of vegetative planting material in many parts of the world, hindering exchange of material between countries.

New methods of long-term germ-plasm storage of vegetative organs therefore are urgently needed. In the interim, current "seed" production practices, such as the use of small corms (cormels) saved from previous harvests, could be improved. Cormels can be stored for as long as 6 months without sprouting, especially if stored at temperatures between 10−15°C with adequate ventilation (Martin 1975).

Identification of all material collected is of primary importance, especially when there is continuous variation of forms, and the need to distinguish cultivars is urgent. Descriptors for *Colocasia* have already been compiled by the International Board for Plant Genetic Resources (AGP, IBPGR/179/52, 1980). This should go a long way in the identification of species and cultivars. Descriptors for *Xanthosoma* are also urgently required. The ISTRC — AB should request IBPGR to undertake this assignment and to enlist the same experts who compiled the descriptors for *Colocasia*.

Evaluation of elite materials should be carried out at different stages, starting at the museum where, until other methods are found, living collections will be maintained from year to year, and moving to the field trials stage involving, for example, studies on water, soil, and nutrient requirements, plant populations, etc. Evaluation should bring out information on maturation time; yield and quality of corms and leaves; palatability of corms, leaves, and petioles and their suitability for local food preparations, etc.; texture, starch, and dry-matter content, etc. of corms; resistance or tolerance to pests and diseases — insects, fungi, bacteria, viruses, and nematodes; and storage life (i.e., how long corms can be stored without sprouting or deterioration). An intensive search should be made for early-maturing (9 months) types that yield well under severe defoliation.

At this stage, it should be possible to identify other institutions willing to cooperate in further evaluations of selected material for suitability to local conditions (i.e., the well-known and tested cooperative trials that IITA carries out with other crops). Local tests should lead to identification and multiplication of the most suitable clones for distribution within the locality. Distribution should include a package of proven agronomic practices — fertilizer, water, etc. — determined during earlier stages and confirmed in the cooperative trials.

PHASE II

A strong physiology program is needed to identify and provide information on important physiologic characters to be used by breeders and agronomists in developing a package of high-yielding varieties and their growing conditions.

Colocasia and *Xanthosoma* show the least capacity for flowering and setting of fertile seed. Breeding and genetic research cannot proceed unless flowering and fruiting occur. There is, therefore, an urgent need to determine the conditions for flowering, fruiting, and seed setting. Techniques for self-pollination and hybridization as well as techniques of seed germination and seedling establishment also have to be worked out.

Work on flowering has been reported by McDavid and Alanu (1976) and on seeds and seedling propagation by Kikuta et al. (1937), Volin and Zettler (1975), and Jackson et al. (1977). Promising results with respect to flowering, pollination, and seed setting of both *Colocasia* and *Xanthosoma* obtained recently at IITA (Annual Report 1978) treating plants with the potassium salt of gibberellic acid (GA_3) indicate that flowering can definitely be induced in plants. Manipulations of such environmental variables as day length and temperature, as well as degrees of shading and defoliation imposed alone and in conjunction with chemical treatment, should also be investigated in attempts to promote flowering and seed setting.

Plantlets or mericlones developed from tissue culture can be used as a means of storing germ plasm as substitutes for living collections, which are rather expensive to maintain. Furthermore, the use of plantlets will greatly facilitate distribution of disease-free material in large quantities throughout the continent. There is a need, therefore, to intensify research in this field. Tissue culture has been used in the propagation of several horticultural species; there are therefore several methods that can be investigated. The earlier work reported by Mapes and Cable (1973) on *Colocasia* should also be investigated and adopted for large-scale multiplication not only for *Colocasia* but also for *Xanthosoma*.

Poor utilization of solar energy by root crops has been the concern of many physiologists. Calculations based on more efficient utilization of available radiation by ideal root crops, i.e., in respect of early groundcover, improved light interception and distribution within the canopy, and improved distribution of dry matter in yield organs, indicate a potential dry-matter production of 550×10^3 cal/ha-day or one-half of gross potential production (de Vries et al. 1967). Under improved growing conditions, production levels by superior cultivars should result in the production of 140 t/ha-year of cassava and 400 t/ha-year sweet potatoes, i.e., an increase of two to three times in the yields of the current high yielders (Wilson 1974).

Theoretically, these yield targets are possible for cocoyams. However, they can only be realized through basic research in crop physiology and especially the utilization of growth analysis techniques to discover, inter alia, cultivars with superior characters in light interception and distribution and, in dry-matter production, distribution, and accumulation in corms early in the growing period. Varieties with these characteristics will have smaller leaves, smaller leaf-area indices, their energy going to initiate corm bulking early. Their corms will attain maximum size early, i.e., they will be early maturing.

Because cocoyams are grown under shade, there is a rapid turnover of leaves, which is confounded by deliberate but unsystematic defoliation for food.

There is, therefore, the need to determine the optimum leaf area and the relationships between leaf area duration and yield, i.e., how often and at what stages of growth should defoliation be made. All these determinations should be made under different shading, moisture, and nutrient regimens. If possible two types should be identified — one type grown for corm yield and one for leaf yield.

There is also the need to determine the best corm conformation. Corm size ranges from one large central corm with a few small side cormels to a medium–small central corm with large numbers of side cormels. Which of these combinations gives higher yields under different growing conditions is uncertain.

In the final analysis it should be possible from such physiologic studies to suggest a basic ideotype to guide selection in breeding programs.

Cocoyams appear to be relatively free from pests and diseases. However, because of the low priority given to these crops in national programs, even those few fungal corm rots and virus diseases have hardly been touched. With large-scale cultivation, pests and diseases will assume greater importance. All accessions should, therefore, be screened for pest and disease resistance.

The research activities by workers from different disciplines should yield results that breeders should digest before embarking upon hybridization programs to combine the useful characters and to develop superior varieties. The development of superior varieties should not lag too far behind the distribution of elite clones from the original germplasm collection. It should dovetail with it so that any enthusiasm generated by the initial program will be maintained.

After the correct choice of parents has been made, hybridization carried out, and seedlings raised, all that will be required is to select promising lines for testing. Testing should involve national institutions throughout the subregions.

ROOT AND STORAGE-ROT DISEASE OF COCOYAM IN NIGERIA

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Symptoms and some aspects of etiology of cocoyam root and storage rot were studied. *Botryodiplodia theobromae*, *Fusarium solani*, *F. moniliforme*, and *Sclerotium rolfsii* were found to be in constant association with storage rot of cocoyam in Nigeria. Field symptoms of the disease included extensive root decay, leaf chlorosis followed by necrosis and shriveling of affected parts, and finally premature death of the aerial portions of the plant. Poor production of cormels and reduced corm sizes were other field symptoms of the disease.

Symptômes et aspects de l'étiologie de la pourriture des racines du taro ainsi que la pourriture en cours de stockage, cette dernière observée régulièrement au Nigeria chez *B. theobromae*, *F. solani*, *F. moniliforme*, et *S. rolfsii*. Sur le terrain, les symptômes de la maladie se manifestent par la pourriture de la racine, la chlorose des feuilles suivie par la nécrose et le dessèchement des parties attaquées pour se terminer par la mort prématurée des parties aériennes de la plante. Parmi les autres symptômes observés, une faible production de tubercules de taille réduite et de bulbilles.

Root and storage rots constitute a major constraint in the production of cocoyam in Nigeria. An estimated loss of 40–45% of corms and cormels was recorded by the National Root Crops Research Institute, Umudike (NRCRI 1979–80). Storage rot of cocoyam has been investigated in many parts of the world where the crop is grown. Wright (1940) described three different types of rot of *Xanthosoma sagittifolium* — dry rot, spongy black rot, and sclerotium rot. Gollifer and Booth (1973b) isolated *Botryodiplodia theobromae*, *Fusarium solani*, and *Sclerotium rolfsii* from stored corms in Solomon Islands. Arene isolated *Corticium rolfsii* (*S. rolfsii*) from rotted leaf bases of cocoyam plants and reported this organism to be the causal agent of the basal rot disease of cocoyam (Arene, personal communication). Also, storage rot of taro, *Colocasia esculenta*, in the Solomon Islands was investigated by Jackson et al. (1975). Trujillo (1967) studied disease of *Colocasia* in the Pacific area. Gollifer and Booth (1973a) reported that *B. theobromae* alone or together with *F. solani* could produce sponge-like rot that occasionally became dry and powdery and ranged in colour from cream–white to light-gray–brown. Viruses have also been implicated. Posnette (1945) suggested that a useful working hypothesis for investigation into root rot of cocoyam was that the primary pathogen was a virus. Although root and storage rots of cocoyam have been studied in many parts of the world where the crop is widely cultivated, I am not aware of similar work reported for Nigeria.

In this paper, the causal agents of root and storage rot of cocoyam in Nigeria are identified and some aspects of etiology and symptomatology described.

MATERIALS AND METHODS

Isolations were made from *X. sagittifolium* and *C. esculenta* respectively. All the organisms identified were sent to the Commonwealth Mycological Institute (CMI), England, for confirmation. Isolations were made from both external and internal corm tissues.

For the external corm tissues isolation, 10 randomly selected corms of *X. sagittifolium* and the same number of *C. esculenta* were used. The corms were washed, first in running tap water for 5 minutes and then in distilled water. Dead leaf scales on each washed corm were carefully removed and transferred to a 25-ml beaker containing 15 ml distilled water. Dead root stumps from each corm were detached and similarly transferred to a 25-ml beaker containing 15 ml distilled water. Both the scale leaves and the root stumps were allowed to steep in the distilled water for 10 minutes, after which they were separately dried on sterile filter papers. Using a scalpel blade, I cut the dead leaves

Table 1. Comparative study on pathogenicity potential of fungal isolates.

	Total rot caused by each treatment (mm)		
	Xanthosoma cv. Ede-Ocha	*Colocasia* cv. Coco-India	Mean
B. theobromae alone	21	54	37.5
F. solani alone	26	39	32.5
F. moniliforme alone	29	29	29.0
S. rolfsii alone	23	76	49.5
B. theobromae + *F. solani*	35	53	44.0
B. theobromae + *S. rolfsii*	27	56	41.5
B. theobromae + *F. moniliforme*	20	26	23.0
F. solani + *F. moniliforme*	31	73	52.0
F. solani + *S. rolfsii*	32	73	52.5
F. moniliforme + *S. rolfsii*	33	71	52.0
F. solani + *F. moniliforme* + *S. rolfsii*	39	80	59.5
Control	0	0	
Mean	27.07		25.54

and root stumps into thin segments about 2 mm long. From each group of samples, 10 segments were randomly selected and plated in potato dextrose agar (PDA). The plates were incubated at 27−28°C for 4 days. On the fifth day, sections of the fungal colonies growing from the various segments of the corm tissues were separately transferred to fresh PDA plates. Transfers were made from the margins of the developing colonies. The transferred cultures were incubated at room temperature (25−26°C) for 21 days and later identified under the microscope primarily on the basis of spore morphology, colour, and types of resistant bodies produced.

Internal tissue isolations were similarly made from 10 corms of *X. sagittifolium* and 10 corms of *C. esculenta* randomly selected from heaps of cocoyam corms that showed partial rots. The corms were washed in running tap water for 10 minutes and later rinsed in distilled water. They were then immersed in 10% Chlorox solution for 15 minutes and, after being rinsed further with distilled water, were dried on sterile filter papers. Using scalpel blades that had been sterilized in 10% Chlorox solution, I sliced thin sections of the corms (*X. sagittifolium* and *C. esculenta*), starting from the "healthy" portion of the corms and sectioning toward the innermost zone of the advancing infection. The cutting blade was disinfected in fresh Chlorox solution after each cut. From the innermost layer of the advancing infection in each corm, four thin slices (1−2 mm) were taken and plated on fresh sterile PDA. The inoculated PDA plates were later incubated at 27−28°C for 4 days. On the fifth day, sections of the fungal mycelium growing from around the plated corm tissues were separately transferred to fresh PDA plates. These plates were then incubated.

Pathogenicity Potentials

The pathogenicity potential of the cocoyam isolates of *B. theobromae*, *F. solani*, *F. moniliforme*, and *S. rolfsii* was studied. Healthy cormels of *X. sagittifolium* variety Ede-Ocha and *C. esculenta* variety Coco-India were inoculated with cultures of these fungi separately and in combinations. Inoculation was effected by introduction of 3-week-old cultures of these fungi separately and in combinations. Each culture plate was marked out into equal segments so that equal amounts of inoculum were used in each case. Each segment was assumed to contain approximately the same quantity of infective propagules. The inoculated cormels were incubated at 27−28°C for 14 days. Each cormel was halved longitudinally and the extent of rot was determined by two diameter measurements. The average of these measurements was recorded. A mean of the measurements of the three cormels was recorded as the amount of rot produced in each treatment. Prior to the measurements, the types of rot produced in the treatments were noted.

Results

Early symptoms of root-rot disease in the field included upward cupping of the leaf margins, pale green leaves, and general slow growth and development. As the disease advanced, leaves became pale and yellowish-green. Meanwhile the laminae

continued to roll upward and inward. In some species of cocoyam that have prominent laminae veins, e.g., Okorokoro and Ede-Ocha (*Xanthosoma* sp.) cultivars, yellowing advanced faster between laminae veins. The chlorotic leaf tissues soon became necrotic and dried portions were easily blown off by the wind, and the infected plant took on a tattered appearance. Leaf chlorosis and necrosis generally progressed inward, finally reaching the leaf stalk. The entire leaf eventually was infected, shriveled, and died. The dead leaf at times stuck upright for a few days before it finally lodged downward. The aerial parts of the plant died 4–6 weeks before normal maturity and gave the general appearance of a heavily infected field by midseason.

Root infections occurred early in plant development, but symptoms on the aerial shoot were manifested much later. Symptoms of the disease were observed as brown lesions on succulent roots. These lesions often girdled the roots, causing the distal ends to nip off. In some cases, where *S. rolfsii* was present, white mycelium of the fungus spread over most of the roots. Under severe infection, most of the early roots rotted, but these were replaced by new roots that proliferated slightly above the zone of infected roots. In severely diseased plants, 80–85% of the roots rotted and the plants were supported by a few fresh roots. One of the characteristic features of cocoyam plants with heavy infection was the ease by which the plants could be pulled from the soil. Harvests from severely infected fields were characterized by scanty production of cormels and much reduced corm size.

Four pathogenic soil-borne fungi that were consistently isolated from harvested corm tissues were *B. theobromae*, *F. solani*, *F. moniliforme*, and *S. rolfsii*. *B. theobromae*, *F. solani*, and *F. moniliforme* were not generally isolated from dead leaf scales or plant debris adhering on the corms, but *S. rolfsii* was. All the fungal isolates inoculated on Ede-Ocha and Coco-India were found to be pathogenic. Each organism caused rot both alone and in combination with others. Generally, more damage was recorded in the Coco-India cultivar than in Ede-Ocha (Table 1). Inoculation with a mixture of *B. theobromae* and *F. moniliforme* produced less rot than did each organism acting independently; however, when Coco-India was inoculated with cultures of the two species of *Fusarium* (*F. solani* and *F. moniliforme*), the amount of rot produced was more than the sum of rots produced separately by these fungi. Maximum rot was produced when all the fungi were interacting. The pathogens produced characteristic rot patterns that were distinguishable from each other in early stages of disease development. However, in combinations with the other fungi, the characteristics of each rot became obscured.

Early in the development of the rot incited by *B. theobromae*, the infected tissues were pale and soft, but, as the disease progressed, the colour changed and the tissues turned dark brown. The zone of infection was easily distinguishable as a dark layer consisting of dead heavily melanized tissues with firm consistency. Infected tissues later became spongy-black, producing a putrefying odour.

Cocoyam rots produced by the two species of *Fusarium* were generally soft but, at the early stages, the cream–dirty-white rot caused by *F. moniliforme* was easily distinguished from the bluish-gray soft rot incited by *F. solani*. Well-defined infection zones were not established. The rotted tissues also produced a putrefying odour at later stages of disease development.

Brown rotting of cocoyam corms and cormels was caused by *S. rolfsii*. Unlike the other types of rot where inoculated fungi proceeded to cause rot deep down the tissues soon after inoculation, the early stages of sclerotium rot consisted of rapid growth and spread of fungal mycelium on the surface of the cormels. The cormels later became soft at the point of inoculations, and as softening spread, the colour continued to change from light brown to deep brown. At this stage, the infected tissues became watery, soft, and pulpy, and a slimy substance with a putrid odour oozed from the point of inoculation. Later the fungus developed dark-brown sclerotia on the surface of the diseased cormels.

DISCUSSION

Results from my study show that four soil-borne fungi are in constant association with root and storage rot of cocoyams in Nigeria. These organisms are *B. theobromae*, *F. solani*, *F. moniliforme*, and *S. rolfsii*. These findings agree in part with the reports from Gollifer and Booth (1973b), who isolated *F. solani*, *S. rolfsii*, and *B. theobromae* from stored corms in the Solomon Islands. Further support comes from Jackson and Gollifer (1975) and D'souza and Moniz (1968) who isolated *B. theobromae* and *F. solani*, respectively from rotted corms. Their results, however, differed from my findings in that my study implicates *F. moniliforme* as well as the other three species in the storage rot of cocoyams in Nigeria.

The general field symptoms described for this disease indicate a phenomenon of interference with the water and mineral absorption system of the

plants' roots. A destruction of 80–85% of the root system was recorded in severely infected plants. Such damage would undoubtedly reduce significantly the absorptive capacity of the plants' roots and create stress on the plants. Severe root rots, coupled with leaf chlorosis, would reduce the ability of the infected plants to absorb mineral nutrients from the soil and to carry out normal photosynthesis. This fact probably accounts for the scanty production of cormels, reduced corm sizes, and generally poor harvest observed from harvests of infected cocoyam plants. Successful isolation of these four fungi from both the internal and external corm tissues has significant epidemiologic implications because it suggests that the mode of transmission of these fungi is through the movement of planting materials. It further indicates that the probable source of inoculum for storage rot is from corms and cormels that become contaminated in the field. Although all the fungal isolates were pathogenic on both *Xanthosoma* sp. and *Colocasia* sp., greater damage occurred in the *Colocasia* (Coco-India cultivar). This finding agrees with the view among many Nigerian cocoyam farmers that Coco-India is more perishable than *Xanthosoma* during storage. The comparative study on the pathogenicity potential of the fungal isolates showed that each organism is capable of causing rot alone or in combination with one or more of the other fungi. This finding is in agreement with Gollifer and Booth (1973a), who found that *B. theobromae* alone or together with *F. solani* could cause a sponge-like rot. My observations of colour changes during corm decay are characteristic of the rot incited by these rot organisms and are in line with reports of other workers: Gollifer and Booth (1972) and Wright (1940). Pathogen interactions were observed when two or more fungi were inoculated together. For example, in the inoculations of Coco-India, the amount of rot produced when one or more fungi interacted with *S. rolfsii* was generally less than the amount produced by *S. rolfsii* alone. In all the inoculations of Coco-India, involving the combination of *S. rolfsii* with other fungi, the activities of *S. rolfsii* were considerably less compared with its actions alone (Table 1). This finding suggests antagonism between the fungi, in which the other organisms gained advantage over *S. rolfsii*. Such antagonism was not observed in the inoculations of corms of Ede-Ocha cultivar. Inoculation with the two species of *Fusarium, F. solani* and *F. moniliforme*, produced rot damage that was greater than the sum of rots of each organism acting independently. This finding indicates that the two species interact synergistically in causing cocoyam rot. I propose three different types of cocoyam rots exist in Nigeria: black rot, fusarium rot, and sclerotium rot. This classification essentially agrees with Wright's classification (1940) that described three different rots of cocoyam as dry rot, spongy-black rot, and sclerotium rot. It is my opinion that whether a rot is dry or not depends largely on environmental factors, such as humidity, presence or absence of free moisture, and the age of the infection. Gollifer and Booth's (1973a) observation that occasionally the sponge-like rot incited by *F. solani* becomes dry and powdery essentially supports this view.

CONCLUSION

B. theobromae, F. solani, F. moniliforme, and *S. rolfsii* are the consistent root and corm-rotting organisms in Nigeria. Each organism produces characteristic rot that differs according to colour. They may act synergistically. When roots are infected, symptoms are leaf chlorosis, shriveling, and premature death of the serial portions of the root, subsequently leading to poor production of cormels and reduced corm size.

FUNGAL ROTTING OF COCOYAMS IN STORAGE IN NIGERIA

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Cocoyam cormels kept in storage barns at Nsukka were examined for rot development. The origin of rot was investigated, and the fungi associated with it were isolated and tested for pathogenicity on cocoyams. Rot initiation occurred mostly from wounds, especially those produced as a result of detachment of cormels from mother corms. *Fusarium solani, Botryodiplodia theobromae, Sclerotium rolfsii*, and *Rhizopus stolonifer* were isolated from the rotting tissue, and inoculation of cormels with each of these fungi resulted in development of rot symptoms. Each of the fungi was consistently reisolated from the rotting tissue arising from inoculation. Rot development was influenced by temperature, the optimum being around 25°C for rots caused by *F. solani, B. theobromae*, and *S. rolfsii*.

Recherche à Nsukka sur la pourriture des bulbilles de taros en cours de stockage. On a découvert l'agent responsable de cette situation: il s'agit d'un champignon qui a pu être isolé et analysé en fonction de sa nature pathogène. La pourriture se développe sur les lésions des tubercules, surtout celles causées par le détachement des bulbilles de la racine-mère. *Fusarium solani, Botryodiplodia theobromae, Sclerotium rolfsii* et *Rhizopus stolonifer* ont été isolés des tubercules attaqués et injectés à des tubercules sains où ils ont déclenché le phénomène de la pourriture. Sur ces racines inoculées, l'agent pathogène a été de nouveau isolé. La température exerce une influence sur le développement de cette maladie, *F. solani, B. theobromae* et *S. solfsii* étant plus actifs à 25°C.

Cocoyams — *Xanthosoma sagittifolium, Colocasia esculenta*, and *C. antiquorum* — are grown in the tropical and subtropical regions of the world as food. They are grown mainly for local consumption and constitute one of the major subsistence crops in these regions. The corms supply easily digestible starch and are known to contain substantial amounts of protein, vitamin C, thiamine, riboflavin, and niacin (Cobley and Steele 1976).

Rotting of cocoyams in storage is a very serious factor limiting the quantity and quality of the crops available for human consumption and for the next planting season. Gollifer and Booth (1973a) reported from their studies in the British Solomon Islands Protectorate that corms of *C. esculenta* rotted and became unfit for human consumption after 1–2 weeks in storage. Jackson and Gollifer (1975) observed that corms began to rot after harvest and became completely decayed within 5 days.

Rots of cocoyams are caused mainly by microorganisms, particularly fungi and bacteria. Harter (1916) reported *Diplodia* sp., *Fusarium solani, Sclerotium rolfsii*, and *Erwinia carotovora* as the causes of storage rots of cocoyams in the USA, and Burton (1970) found *Botrytis* sp., *Fusarium* spp., *Rhizoctonia* sp., and *Roselinia bunodes* to be the pathogens causing rotting of *C. esculenta* corms at the Chicago market. In India, *Botryodiplodia theobromae* was found to be the pathogen causing corm rot of *C. antiquorum* (D'Souza and Moniz 1968), whereas in Egypt, *F. solani* was the main cause of storage rot (Michail et al. 1969). In the British Solomon Islands Protectorate, the organisms responsible for storage rotting of *C. esculenta* corms were *F. solani, B. theobromae*, and *S. rolfsii* (Gollifer and Booth 1973a). However, later studies from that area (Jackson and Gollifer 1975) have shown that *Phytophthora colocasiae* and *Phythium splendens* were the principal fungi involved in initial stages of decay. Bacterial soft rot caused by *Erwinia chrysanthemi* was also reported to be serious in *C. esculenta* corms stored in pits (Jackson and Gollifer 1975).

Cocoyam is a major food crop in Nigeria, especially in the southern part where it is cultivated extensively for local consumption. It is harvested mostly in December and January and is kept in storage for food and for the next planting, which takes place usually in May and June. In storage, serious rotting of the crop is commonly observed, but very little is known about the factors responsible for it. Ogundana (1976) reported *F. moniliforme* and *F. solani* as causing rot of *X. sagit-*

tifolium, with *S. rolfsii* and *Trichoderma hamatum* behaving as weak pathogens. However, this pioneer report has not been corroborated by contributions from other workers in Nigeria. Besides, there is no available information on the microorganisms causing storage rot of *C. esculenta* in the country. Recently, studies were carried out at Nsukka on fungal rotting of *C. esculenta* and *X. sagittifolium* in storage. This paper reports these studies. An abstract of some of the aspects has been published elsewhere (Maduewesi 1978).

MATERIALS AND METHODS

Freshly harvested cocoyams — *X. sagittifolium* Nsukka variety and *C. esculenta* Ugwuta variety — were procured from the Nsukka market for use in this study. Detached cormels of the two cultivars were heaped on the floor of a barn in the botanic garden of the University of Nigeria and were examined weekly for 10 weeks (January–March) for development of rot. The experiment was repeated in 2 successive years for 12–16 weeks from January to April. The cormels in which rots were beginning to develop were selected and sectioned longitudinally through the rotted spot. They were then examined carefully so that the origin of the rots could be ascertained and the rot symptoms recorded. Cormels showing advanced stages of rots were also sectioned for observation of rot symptoms.

ISOLATION OF FUNGI

Small sections of cocoyam tissue containing the advancing margin of rot and the adjoining healthy tissue were surface sterilized, being first immersed in 0.9% mercuric chloride solution for 1 minute and, then, rinsed in two changes of sterile distilled water. Next, they were cultured on water agar (WA) and incubated in the dark in a refrigerated incubator maintained at 25°C for 3 days. The mycelium developing from the tissue sections was transferred to potato dextrose agar (PDA). Several transfers of mycelium were made from WA to PDA and from PDA to PDA until pure cultures of the isolated fungi were obtained. The fungi were later identified.

INOCULATION OF COCOYAMS

Medium-sized, sound cormels free from wounds were selected for uniformity from a large collection. The cormels were cleaned and surface-sterilized with 5% Chlorox solution for 5 minutes. Care was taken in handling of the cormels so that they were not wounded.

To test the pathogenicity of the isolated fungi, we cultured the fungi on PDA in petri dishes and used the developing mycelium to inoculate the cocoyams. The inocula consisted of discs of mycelium 4 mm in diameter cut from the periphery of actively growing cultures of the fungi. The method employed for inoculating the cocoyam with each fungus was similar to that described previously for inoculating the yam (Adeniji 1970). The fungal culture disc was placed inside the hole in the cocoyam tissue after the core of cocoyam tissue had been removed with a sterile 5-mm cork borer. The core of tissue was cut in two, and the halves were placed in the hole as plugs for both ends. The replaced core of tissue at each end was sealed with cellotape. Discs of sterile PDA 4 mm in diameter were used as control. Each fungus was used to inoculate 10 cocoyams.

The inoculated cocoyams were kept on a raised platform in the barn for 9 days. The barn temperature during the period was 28 ± 2°C. The cocoyams were then cut and the extent of rot was assessed. The cuts were at right angles to the holes through which the inocula were introduced. Measurements of linear development of rot were taken along two radii of rotted area at right angles to each other and their average recorded. The study was carried out three times.

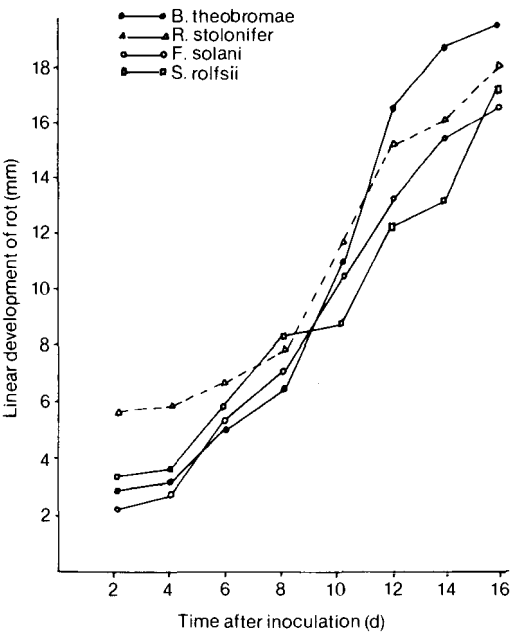

Fig. 1. *Time course of rot development in* C. esculenta *inoculated with four fungi.*

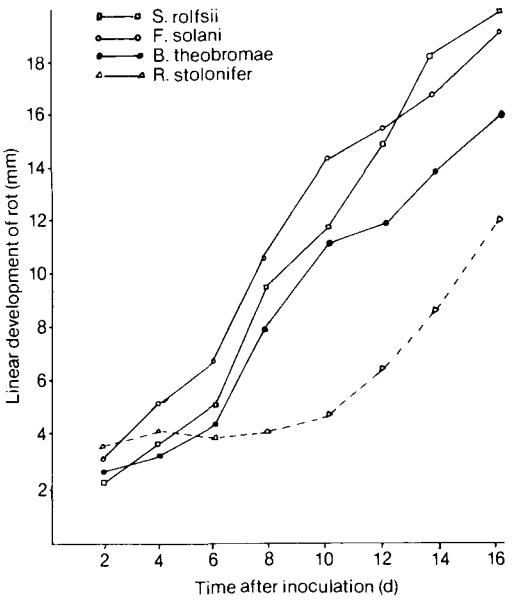

Fig. 2. *Time course of rot development in* X. sagittifolium *inoculated with four fungi.*

Reisolation of Fungi and Reinoculation

Using a flamed scalpel, we cut small sections of the rotted areas next to healthy tissues and cultured them in water agar medium in petri dishes. The fungi developing from them were transferred to PDA and later compared with the fungi previously isolated from diseased cocoyam.

To observe how the rot of cocoyam in storage progressed with time, we selected cocoyam cormels, surface-sterilized them, and inoculated each with an isolated fungus. The inoculated cocoyams were kept on a raised platform inside the barn. At 2-day intervals for 16 days following inoculation, five inoculated cocoyams were randomly selected from each set of cocoyams inoculated with each fungus. The extent of rot development was measured on each occasion. To determine the effect of temperature on rot development, we incubated inoculated cocoyams for 7 days at 10°C, 15°C, 20°C, 25°C, 30°C, and 35°C in the dark, using refrigerated incubators. The extent of rot development after 7 days was measured. The test was carried out three times.

Results

Rots of stored cocoyams (*C. esculenta*) were initiated mostly from wounds arising from detachment of cormels from mother corms, harvest bruises, or other injuries. Of 1652 cases of rot, which were observed at the early stage of development from 1652 cormels, 1027 (62.2%) originated from the bases (i.e., ends previously attached to mother corms), 499 (30.2%) from surface wounds, 81 (4.9%) from the tops, and 15 (0.9%) from nematode galls. The origin of rot in 30 cases (1.8%) was not clear.

Rot Symptoms

Rots at different stages of development were observed in the cocoyams (*C. esculenta* and *X. sagittifolium*) kept in storage. The rots were of two main types — dry rot and wet rot. The diseased tissue in the case of dry rot was dry, firm, or caky. In the case of wet rot, the diseased tissue was soft and frequently wet. The colour of the cocoyam tissue during the course of rot changed progressively, moving from cream white to various shades of brown or gray and terminating in dark brown or gray-blue. In some cases, fungal structures in the form of white mycelial cover or brown sclerotia were seen on the surface of the rotted cocoyam.

The Fungi

The fungi isolated from diseased cocoyam tissues were identified as *F. solani*, *B. theobromae*, *S. rolfsii* stage of *Corticium rolfsii*, and *R. stolonifer*. Isolates of *F. solani* and *B. theobromae*

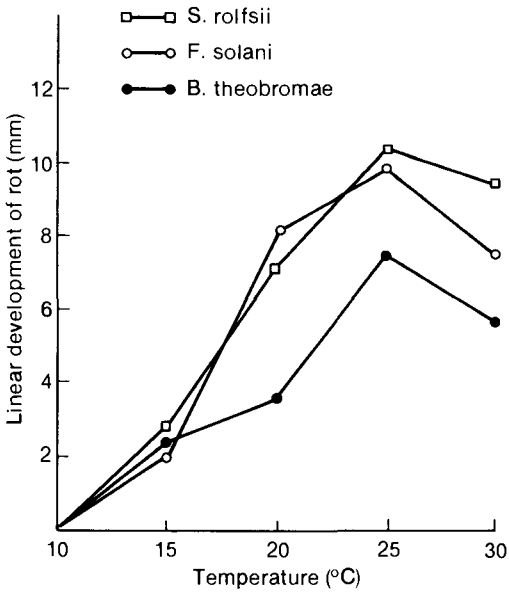

Fig. 3. *Effect of temperature on rot development in* X. sagittifolium *inoculated with three fungi.*

were commonly obtained from dry rots of *C. esculenta* and *X. sagittifolium* but occasionally from soft rot of these species. Isolates of *S. rolfsii* were frequently obtained from soft rots of the two cocoyam species, whereas *R. stolonifer* was isolated only from soft rot of *C. esculenta*.

The pathogenicity of each of these fungi on cocoyam was proved. Each fungus caused rotting of cormels of both cocoyam species after inoculation. Each fungus was also reisolated from the rotted tissue. Watery soft rot, dirty white to light brown, was observed in cocoyams inoculated with *S. rolfsii*. Those inoculated with *F. solani* or *R. stolonifer* developed brownish rots, whereas those inoculated with *B. theobromae* produced gray-blue rots.

Rot symptoms were observed in cormels as early as 4 days after they were inoculated with the fungi and kept in the barn, but the extent of rot development increased with time (Fig. 1 and 2).

Rotting in corms of *X. sagittifolium* inoculated with *S. rolfsii*, *F. solani*, or *B. theobromae* and incubated for 7 days was greatest at 25°C (Fig. 3). External mycelial coating of *S. rolfsii* was observed on the cocoyam inoculated with *S. rolfsii* and incubated at 20°C for 7 days.

DISCUSSION

The results of this study have shown that *F. solani*, *B. theobromae*, *S. rolfsii*, and *R. stolonifer* cause storage rot of *C. esculenta* and *X. sagittifolium* in Nigeria. Of these fungal pathogens, only *F. solani* and *S. rolfsii* were reported previously as causing rot of *X. sagittifolium* in Nigeria (Ogundana 1976). However, reports from other countries have shown that *F. solani*, *B. theobromae*, and *S. rolfsii* are storage-rot pathogens of cocoyams (Gollifer and Booth 1973a,b; Harter 1916; Jackson and Gollifer 1975). An unidentified *Rhizopus* sp. has been shown to cause rot of *X. sagittifolium* (Burton 1970), but our report appears to be the first to show that *R. stolonifer* causes rot of *C. esculenta*.

The results of our study showed that storage rots of detached cormels of cocoyam originate mostly from the base and from the wounded surfaces of cormels. Because the base of the cormel has a distinct wound, produced as a result of its being detached from the mother corm, we conclude that the storage rot pathogens are essentially wound parasites. Previous workers (Gollifer and Booth 1973a; Harter 1916; Ogundana 1976) arrived at a similar conclusion based on observations made on storage rot of cocoyam corms. It follows that storage rots of cocoyams would be significantly reduced if wounding is avoided during and after harvesting.

The results showed that temperature influences rot development. The optimum temperature for rot of *C. esculenta* caused by *S. rolfsii*, *B. theobromae*, and *F. solani* was about 25°C. There was no rot at 10°C and little at 15°C. Ogundana (1976) reported an optimum temperature range of 26–30°C for rot of *X. sagittifolium* caused by *F. solani* and *F. moniliforme*. Burton (1970) reported 22–29°C as optimal for the cocoyam-rot pathogens. These results indicate that rot caused by *F. solani*, *B. theobromae*, and *S. rolfsii* would be minimized if cocoyams were stored at lower temperatures such as 10–15°C, that do not cause injury to the tissues.

We thank the Director and the staff of the Commonwealth Mycological Institute for identifying the species of fungi reported in this paper and the Senate Research Grant Committee of the University of Nigeria for financial support.

A DISEASE OF COCOYAM IN NIGERIA CAUSED BY *CORTICIUM ROLFSII*

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In the rain-forest zone of Nigeria, *Corticium rolfsii* disease of cocoyam is widespread and has been well known since 1954. The field symptom is sudden collapse of the outer petiole from the base due to the maceration of the tissues by the pathogen. Infected corm exhibits cheesy rot and the periderm is encrusted with the fungal mycelial mat. Yield losses could be up to 90%. Soil inoculum is reduced by grass mulch and monocrops of maize. Farmers may reduce disease by hilling but enhance it by narrow spacing. Planting deep reduces field rot and increases corm yield. Increased disease severity in the field increases storage rot and reduces sprouting. Storage of *Xanthosoma sagittifolium* on uncovered raised rafters and *Colocasia esculenta* in soil pits or baskets ashed and covered with fresh pieces of plantain trunk reduces corm rot. Varietal differences exist for resistance and yield.

C. rolfsii est une maladie du taro très répandue depuis 1954 dans les zones des forêts humides du Nigeria. Elle se manifeste par la chute soudaine du pétiole externe qui se détache de la base, les tissus ayant été attaqués par le pathogène. Les tubercules infestés sont caséeux et le périderme couvert d'une croûte de blanc de champignons. Les pertes peuvent s'élever jusqu'à 90% de la récolte. Le paillage peut réduire la contamination du sol ainsi que la production du maïs en culture pure. Le buttage peut également limiter la contamination mais les plants trop rapprochés la favorisent. La plantation en profondeur est une mesure de lutte efficace qui favorise également la croissance des tubercules. Une attaque sévère dans le champ est un risque de pourriture plus grand pour les tubercules stockés et de plus, elle réduit la germination. Le stockage de *Xanthosoma sagittifolium* sur des billions et à l'air libre et de *Colocasia esculenta* dans des fosses de terre ou des paniers, cendrés et couverts d'écorce fraîche et de plantain protègent les tubercules de la pourriture. Les caractères de résistance et de rendement diffèrent d'une variété à l'autre.

Cocoyam, primarily *Colocasia esculenta* and *Xanthosoma sagittifolium*, together with yams (*Dioscorea* spp.), cassava, and sweet potato (*Ipomoea batatas*) as root and tuber crops form the major carbohydrate source in Nigeria. In 1975–76, the country produced 1.0856 Mt of cocoyams. But in 1972, it was estimated that the demand for cocoyams by 1985 would necessitate an annual compound growth rate of 3.5 (Olayide et al. 1972). Yet, since 1974, there have been reports of steady decline in the crop production in the country (Federal Office of Statistics 1978).

Appraisal of the constraints on cocoyam production indicates that it is not so much a lack of demand as losses due to field diseases and postharvest deterioration. Losses in storage greater than 50% are common and are known to be primarily due to microorganisms, such as *Sclerotium rolfsii*, the imperfect stage of *Corticium rolfsii* (Ogundana 1976; NRCRI 1975, 1976).

This disease on cocoyam has been known to occur in Ghana (Doku 1967), and the Pacific areas (Fajardo and Mendoza 1935; Parris 1941; Dambleton 1954; Trujillo 1967); however, in none of these areas has the disease syndrome in the field been described. A broad range of fungicides have been shown to be ineffective in prevention of corm rot induced by the pathogen (Jackson and Gollifer 1975).

Several storage methods have been practiced with various degrees of success in preventing storage rots. In Polynesia and in the Solomon Islands, corm is stored in soil pits (Gollifer and Booth 1973a). In Nigeria it is generally stored in soil pits, on rafters, or heaped on barn floors and covered. The effects of these indigenous methods of storage have not been quantified.

This paper presents an overview of studies done to date on the *C. rolfsii* disease of the crop and the possible control measures both in the field and in storage.

The mycelial mat of *S. rolfsii*, the imperfect stage of *C. rolfsii*, was first observed on decaying cocoyam corms in Ghana by Dade in 1925 (Doku

Table 1. Occurrence of *Corticium rolfsii* disease of cocoyam in local government areas of states in Nigeria, 1979.[a]

State	Local govt. area	Town	Occurrence		Local name(s) of disease	Year first observed
			Xanthosoma sp.	*Colocasia* sp.		
Anambra	Anambra	–	+ + + (FS)	-	–	1970
Anambra	Aguata	Nanka	-	+ + + (S)	"Ule Ede"	1965
Bendel	Ika	Agbor	-	+ (FS)	"Ure Akasi"	–
Bendel	Etsako	Ishan-Ekpoma	+ (F)	+ (FS)	–	1954
Benue	–	–	-	-	–	–
Imo	Ohaji/Egbema/ Oguta	–	-	+ + (FS)	–	1960
Imo	Isiala Ngwa	–	+ (FS)	+ (FS)	"Oria Ede"	1973
Imo	Umuahia/ Igwuano	Umuahia	+ + (FS)	+ + + (FS)	"Ogba Oku"	1972
		Umudike	+ + (FS)	+ + + (FS)	–	1967
Imo	Okigwe	Okigwe	-	+ + + (FS)	–	1967
Rivers	Yenagoa	–	+ + (FS)	+ + (FS)	"Bukolu" "Okire"	1977
Rivers	Bori	–	+ + + (FS)	+ + + (FS)	"U-togoh"	1975
Oyo	–	Ibadan	+ + (S)	+ + (S)	–	1972
Plateau	–	–	-	-	–	–
Niger	–	–	-	-	–	–
Kaduna	–	–	-	-	–	–
Cross River	–	Ikot-Ekpene	+ + + (FS)	+ + + (FS)	–	1964
Ogun	–	–	-	-	–	–

[a] + + + = very widely spread; + + = widely spread; + = not widely spread; - = not observed; F = field; S = storage; and FS = field and storage.

1967). Such cocoyams were known previously to be diseased by an unknown malady (Posnette 1945). In 1966, *S. rolfsii* was recorded as a tuber-rot pathogen of *C. esculenta* variety Antiquorum in Nigeria (Bailey 1966). In Fiji, Hawaii, and the Philippines, it had caused corm rot on the crop (Trujillo 1967). *X. sagittifolium* was included as a host of the pathogen in Nigeria when 109 possible hosts of cowpea isolate of *S. rolfsii* were tested on crops (Maduewesi 1975). However, our survey of the disease occurrence in Nigeria showed that as far back as 1954 the disease was known in Ishan-Ekpoma in Etsako area of Bendel State where field and storage symptoms had been observed in both *X. sagittifolium* and *C. esculenta* (Table 1). In 1955, field and storage symptoms were observed in Bori area of Rivers State in the two species. By the 1960s it had been recorded in Anambra, Imo, and Cross River State. All these were before Bailey recorded it in 1966.

In most of the areas where the disease was reported, local names for it exist and are very descriptive. These names include *Ule Ede* (Ibo), *Ule Akasi* (Ika Ibo), *Oria Ede* (Ibo), *Bokulu* (Yenagoa), and *U-togah* (Seri), which all mean either cocoyam rot or blighting. From these various descriptive names, it is apparent that the Nigerian farmer has been aware of the disease and its economic importance for a long time.

GEOGRAPHIC DISTRIBUTION

The disease appears predominant in the rain-forest area of the country stretching from Lagos in the West across the River Niger to the East through the Cross River State. It also occurs along the transitional zones, in the north of the rain forest and Guinea savanna; and in the south of the rain forest and swamp forest. These areas correspond to the zones with temperatures of 22°C and 30°C and annual rainfall of about 2000 mm.

Higgins (1927) had suggested that the distribution of *C. rolfsii* is restricted by temperature requirements. The minimum, optimum, and maximum temperature requirements for mycelial growth and pathogenesis are 8, 30–35, and 40°C, respectively (Higgins 1927). The longevity of the mycelium is increased under cool, dry air and at 32°C with 50% RH and above, it fails to survive more than a month's storage (Epps et al. 1951). It has also been shown that at 50°C, the highly resistant dry sclerotia are inactivated after 80 min (Maduewesi 1974). Thus, it is apparent that the

disease would abound in the rain-forest zone in the country where the minimum and maximum annual temperatures are 22°C and 33°C respectively. In the savanna zones the maximum temperature, 34°C, persists for most of the year; thus this area does not favour the pathogen. In this zone also, the paucity of tree shade may be a deterrent to the disease. It is not surprising, therefore, that the disease is found mostly in the rain-forest zone where ideal temperatures for growth and pathogenesis of the disease exist. In the swamp forest, the high mean annual rainfall with the concomitant high humidity is not ideal for mycelial growth and pathogenic attack.

PATHOGENESIS

The pathogen does not require wounds to penetrate the crop. It can attack through intact surfaces (Table 2). Initial infection, however, requires a good inoculum, which is provided by accumulation of vigorously growing mycelial mat on suitable substrate, such as mature petiole pieces (Table 2). It may attack the crop at any stage of growth (Table 3). However, the highest attack is among 5–6-month-old plants. When the plant is attacked very early, especially at planting, it may be killed outright, the cocoyam seedling damping off. However, the pathogen attacks older tissues in preference to young, vigorously growing ones (Table 3). Damping off of the seedling observed when infection occurred at planting is probably due to the destruction of the planting material and the reduction of its energy for sprouting or establishment.

The symptoms on the cocoyam crop are very distinct. The most important is the sudden collapse of an apparently healthy outer petiole. The petiole often exhibits tattered basal edges that indicate the area of attack invariably upon the older organs and tissues. The tattered edges may also be accompanied by wet rot, especially during wet weather. The base of the infected petiole is encrusted with white mat of the fungal mycelium, which is dotted with sclerotia at different stages of maturity. The mycelium with its dots of sclerotia may radiate some centimetres up the base of the affected plant and outward on the soil surface. Hence the collapsed petiole with the mycelium radiating along it from the proximal to the distal end may serve as a bridge for spreading the pathogen from one crop to another in the field (short distances) or may be moved from one field to another (long distances) when the soil and debris are moved. Rain splashes or flooding may also carry the fungus on the soil surface from one field to another.

Table 2. Infectivity of different inoculum sources of *C. rolfsii* and interaction with two species of cocoyam.[a]

	Plants infected (%)		Mean % for both species
	X. sagittifolium	*C. esculenta*	
Infection	26.25a	20.63a	
Sclerotium	–	–	15.00a
Mycelium	–	–	10.63a
Inoculum cube	–	–	68.13b
Control	0.00a	0.00a	0.00a
Wound	17.50a	35.00b	31.88a
No wound	12.50a	28.75ab	15.00a

[a]Means not followed by the same letter are statistically different at the 5% level of probability.

Table 3. Infectivity of *C. rolfsii* on two cocoyam species of different ages.[a]

Age (months)	Mean % of both species infected	Plants infected (%)	
		X. sagittifolium	*C. esculenta*
0	35.00ab	40.00ab	30.00b
1	17.00b	20.00c	15.00c
2	17.50b	25.00bc	10.00c
3	40.00a	40.00ab	40.00ab
4	40.00a	40.00ab	40.00ab
5	40.00a	50.00a	30.00b

[a]Means not followed by the same letter are statistically different at the 5% level of probability.

The symptoms on the corm are typified by cheesy rot of the central portion of the flesh with the surface of the periderm encrusted with fungal mycelial mat. Sclerotia, typical of the fungus, may appear on the mat during warm, humid weather. The pathogen may, therefore, be inadvertently transferred on the corm surfaces from the field to a storage barn where postharvest rot of the harvest may be initiated.

Histopathologic studies show that the fungus attacks the cocoyam crop with no infection peg. The mycelial mat accumulated as infection cushion on the infection court and liquefaction of the court are initiated as tiny brownish water-soaked lesions. These eventually lead to the maceration and penetration of the hyphae into the tissue. Once inside the tissue the hyphae grow intercellularly and intracellularly. Within a distance of 25–40 mm, water-soaked discoloration of the tissue indicates initial symptom development; presence of mycelium inside the tissue is observed only from 25 to 35 mm. Liquefaction of the best tissue is in advance of the invading hyphae, thus suggesting that the fun-

gus produces exogenous macerating substances. Oxalic acid and other enzymes for carbohydrate metabolism have been shown to be produced by the fungus as the necrotic substances (Higgins 1927; Weber 1931; Johnson and Joham 1954). This mode of parasitism is not unique to *C. rolfsii*. It has been suggested that some facultative parasites are really saprophytes that have to kill the tissues before feeding on them (Stockman and Harrar 1957).

A positive trend exists between disease severity and the yield in the two cultivars of *X. sagittifolium* (Table 4). Highest yield is obtained where there are the highest number of petioles present and lowest yield, with the least number of petioles. No field corm rot is observed in any of the classes. Similarly, the same trend exists in the cultivars of *C. esculenta* (Table 4). However, with reduction in number of petioles, field rot increases in the species. A high negative trend exists between the field rot and yield in each of the cultivars of this species. Thus the group with the lowest yield is the group with the highest severity (least number of petioles present). It is judicious, therefore, to rank the ranges of the number of leaves from healthy to most severely affected and use the ranks as measures of disease severity. Use has been made of standard deviation and grand mean to classify severity (Doreste et al. 1978). As the coefficient of variation shown in the tables shows conditions of uniformity in the field, severity of this disease has been classified on the basis of mean number of leaves (X) and standard deviation (S); highly resistant (1) corresponds to X + 2S; resistant (2) to X + S; tolerant (3) to X; susceptible (4) to X−S; and very susceptible (5) to X−2S. This classification is for use in screening for resistance. The threshold of significant losses is in classes 4 and 5 where losses in yield as high as 80% are observed in *X. sagittifolium* and 50−60% in *C. esculenta*.

CULTURAL MANAGEMENT

C. rolfsii populations are known to be highest in sandy loam and sandy-clay loam soils previously monocropped with cocoyam and lowest in maize monocropped plots (Arene 1980) (Table 5). In both soil types, when the field has been previously monocropped with cocoyam with high *C. rolfsii* populations, disease severity is highest. Conversely, the disease severity is least on maize monocropped plots where *C. rolfsii* populations are lowest. Soil type does not affect severity.

Root excretions into the rhizosphere of some resistant varieties of crops often support the growth of organisms antagonistic to *C. rolfsii* (Timonin 1941; Lockhead et al. 1940; Rovira 1956; Anyanru 1976; Buxton 1957). It is possible, therefore, that maize, yam, and *Eupatorium*, that are resistant to *C. rolfsii* (Maduewesi 1975) secrete substances enhancing the growth of the antagonists of this pathogen. Whatever the explanation, maize, 2-year *Eupatorium* fallow, and yam lower the inoculum potential of *C. rolfsii*, whereas cocoyam and cassava enhance it.

It is pertinent to be judicious in selection of crop mixtures and rotation patterns that are adaptable to diverse soil types and that will reduce the disease incidence.

Disease severity of *C. rolfsii* is reduced with grass mulch in both sandy loam and sandy-clay loam soils (Table 6). Reduction of diseases by suitable mulch is not peculiar. Alfalfa meal reduces *C. rolfsii* disease by increasing the disintegration of the sclerotia (Johnson 1953). Soybean tops induce rapid reproduction of harmless organisms, whereas timothy and red clover have no such effect (Pollard 1945). Oat straw increases the propagule of *Fusarium solani*, the bean rot pathogen (Papavizas et al. 1968).

Table 4. Petioles, yield, and field rot per stand of two cultivars of *X. sagittifolium* (Ede Ocha and Ede Uhie) and *C. esculenta* (Ede Ukwu and Ede India) classified by severity of infection with *C. rolfsii*.[a]

	Ede Ocha			Ede Uhie			Ede Ukwu			Ede India		
Severity	Petioles	Yield (kg)	Field rot (%)	Petioles	Yield (kg)	Field rot (%)	Petioles	Yield (kg)	Field rot (%)	Petioles	Yield (kg)	Field rot (%)
1	6.8a	2.06a	0	8.5a	2.21a	0	32.8a	1.59a	0a	35.3a	1.86a	0a
2	5.6a	0.92a	0	5.7b	1.54b	0	24.6b	1.18a	0a	24.0b	1.20b	0a
3	3.7b	0.78a	0	3.6c	0.95b	0	19.2b	0.90b	30.96b	18.0c	0.94bc	23.64a
4	3.1b	0.54ab	0	2.9c	0.52c	0	7.5c	0.84b	40.75b	9.0d	0.68c	57.41b
5	1.5c	0.37b	0	1.7d	0.22c	0	4.6c	0.34c	39.78b	9.5d	0.54c	40.75ab

[a]Means in the same column followed by the same letter are not statistically different at the 1% level of probability; coefficients of variation are 19.3% for Ede Ocha, 16.3% for Ede Uhie, 27.5% for Ede Ukwu, and 24.7% for Ede India.

Table 5. *C. rolfsii* content of sandy loam and sandy clay loam soils monocropped a year before with different crops as determined by percent of "baiters" infected.[a]

Previous crop	Baiters infected (%)	
	Sandy loam	Sandy clay loam
Maize	5.00	5.00
Cocoyam	17.50	25.00
Yam	5.00	15.00
Cassava	7.50	15.00
Fallow (*Eupatorium* sp.)	7.50	15.00

[a]Mean of four replicates; LSD at a 5% level of probability is 21.09.

A high carbon : nitrogen ratio in the soil inhibits the infectivity of *C. rolfsii* (Curl et al. 1968) and has been associated with a slow decomposition of organic matter in the soil (Alexander 1961; Black 1968). This is dependent, among other factors, on the lignin content of the material. We observed that decomposition of the grass mulch was slower than was that of *Eupatorium*. It is possible, therefore, that the grass mulch reduces the pathogenic activity of the fungi by increasing the soil C : N ratio. Slowly decomposing mulch may, therefore, assist in reducing the disease.

Disease incidence is reduced at very narrow and very wide spacings, but severity is highest at very narrow spacings (Table 7). Field corm rot is reduced and yield enhanced when planting is deep. These observations have been explained in relation to the ecology of the pathogen and the morphology of the crop (Arene 1980). The reduced incidence at narrow spacings may be due to the high humidity developed under the plant microclimate by the crowded canopy and at wide spacings to desiccation by solar radiation. Both high humidity and desiccation are known to be unfavourable to the growth and pathogenesis of *C. rolfsii* (Boyle 1961). The highest severity of the disease at very narrow spacing may result from population stress that weakens the plant. The high prevalence of field corm rot with shallow planting is probably due to the exposure of the corm to solar radiation, which induces physiologic rot of the crop. Solar radiation is a predisposing factor to biodeterioration, thus the increased field corm rot with shallow planting. Production of cormels is known to be enhanced by the depth of the corm. Thus, it is general practice in Nigeria to hill cocoyam as soon as cormel formation starts. That deep planting increases yield is, therefore, not odd.

Though yield and stand increase with deep planting at wide spacings (Table 7), the best total yield per hectare is achieved at very narrow spacings. However, this is accompanied by a decrease in corm size.

Hilling also reduces the incidence of *C. rolfsii*; it involves amassing soil and weeded debris around the base of the crop, covering most of the organic matter, and thus depleting the surface of the organic matter needed for the vigorous mycelial growth and

Table 6. Severity of *C. rolfsii* disease on *X. sagittifolium* (Ede Uhie) and *C. esculenta* (Ede Ukwu) as affected by two soils and two mulches (figures in parentheses are for controls).

	Severity of infection	
	Ede Uhie	Ede Ukwu
Sandy loam	3.08 (3.25)	1.6 (2.00)
Grass	2.50	1.25
Eupatorium	3.50	1.25
Sandy clay loam	2.91 (2.75)	1.4 (1.75)
Grass	2.75	1.00
Eupatorium	3.25	1.50

Table 7. Mean incidence, severity, field rot, and yield as affected by variety, spacing, and planting depth.[a]

	Incidence (%)		Severity		Field rot (%)		Yield/stand (kg)	
	1978	1979	1978	1979	1978	1979	1978	1979
Ede Ocha	55.5ab	33.11a	2.53a	3.56a	0.79a	27.19a	0.87a	0.28a
Ede Uhie	71.6a	36.23a	2.63a	2.87ab	0.82a	24.08a	0.81a	0.47ab
Ede Ukwu	58.5a	35.37a	1.43c	1.90b	15.23b	32.00a	1.13b	0.75b
Ede India	35.7b	22.36b	1.85b	2.97ab	14.13b	30.00a	0.75a	0.33a
60 × 100 cm^2	46.2a	31.09a	2.07a	3.15a	8.34a	28.29a	0.79a	0.34a
80 × 100 cm^2	62.1a	33.59a	2.12a	2.75ab	8.42a	29.34a	0.98b	0.48ab
100 × 100 cm^2	58.0a	31.20a	2.13a	2.58b	7.48a	27.75a	0.91ab	0.55b
Partially buried	56.9a	45.39a	2.14a	2.82a	9.42a	31.83a	0.79a	0.43a
Completely buried	54.0a	49.92a	2.07a	2.83a	6.07b	25.08b	0.99b	0.53a

[a]Means within the same column not followed by the same letter are statistically different at a 5% level of probability.

Table 8. Mean incidence, severity, field rot, and yield as affected by variety, weed control, and hilling.[a]

	Incidence (%)		Severity		Field rot (%)		Yield/stand (kg)	
	1978	1979	1978	1979	1978	1979	1978	1979
Ede Ocha	82.3a	38.01ab	3.85b	3.04b	1.53a	38.68b	1.30a	0.45a
Ede Uhie	86.9a	32.77ab	3.20b	2.58ab	4.75a	30.75a	1.28a	0.61a
Ede Ukwu	85.7a	43.62a	1.4a	1.91a	25.01b	26.06a	1.33a	1.05b
Ede India	62.8b	29.95b	1.6a	2.71ab	32.35b	35.50ab	0.99b	0.58a
Hoe weeding	74.9a	35.61a	2.72a	2.42a	16.54a	32.62a	1.26a	0.66a
Hoe weeding/ preemergence herbicide	84.9a	36.00a	2.80a	2.70a	15.28a	32.87a	1.19a	0.71a
Hilled	79.9a	33.31b	2.57a	2.33a	15.48a	28.37a	1.24a	0.76b
Not hilled	80.9a	38.31a	2.95a	2.79b	16.41a	37.37b	1.22a	0.58a

[a]Means within the same column not followed by the same letter are statistically different at a 5% level of probability.

attack by the pathogen (Table 8). Although some workers have shown that excessive hilling results in the amassing of organic debris that is food for the pathogen of stem rot in peanuts (Wells and Cooper 1952), our work is not contradictory. We have found that the type of organic matter like the type of mulch amassed around a crop determines whether the disease will be reduced or increased. For example, grass decomposes slowly and reduces the disease in cocoyam; however, *Eupatorium* decomposes quickly, and allows the disease to progress.

Diuron per se does not affect the disease nor the yield. Yield, however, is increased and field corm rot reduced by hilling. As hilling results in deeper burial of the corms, it is not surprising that corm field rot is reduced.

Selection of Resistant Varieties

Though it is known that the *C. rolfsii* has a very wide host range (Boyle 1961), resistance has been recorded in some crop varieties (Epps et al. 1951). The varietal differences in response to the disease indicate that resistant varieties exist also in cocoyam. A combination of high-yield and resistance is noted in *C. esculenta* cultivar Ede Ukwu. Thus, it is possible to select high-yielding, resistant varieties as a means of controlling this disease. It is also feasible to incorporate high yield with resistance to the disease through breeding. The potential of inducing flowering in cocoyam has been demonstrated at IITA by using gibberellic acid.

Table 9. Loss in weight of two cultivars of *X. sagittifolium* (Ede Ocha and Ede Uhie) and *C. esculenta* (Ede India and Ede Ukwu) after 6 and 12 weeks of storage.

	Storage (weeks)	
Cultivar	6	12
Ede Ocha	35	86
Ede Uhie	70	96
Ede India	30	68
Ede Ukwu	60	63

Postharvest Management and Control

C. rolfsii disease attack in the field has earlier been shown to lead to total crop failure due to damping off or losses in corm yield of 80–90% in *X. sagittifolium* and 50–60% in *C. esculenta*. Sprouting ability of affected corms decreases with severity of the disease. An explanation is that the pathogen usurps the energy available for sprouting (Arene 1980). The optimum temperature for corm rot due to this pathogen is 30–35°C. Increased humidity enhances corm rot in *X. sagittifolium* but reduces it in *C. esculenta*.

Working with *X. sagittifolium*, Ogundana (1976) observed that corm rot was reduced when the corms were stored below 50% RH. This finding agrees with observations in *C. esculenta* by Gollifer and Booth (1973a), who worked primarily with *F. moniliforme* and *B. theobromae*. These two pathogens are characterized by production of spores that require high humidity for dispersal, germination, and penetration of the host (Cochrane 1958). It is plausible that rot induced by these pathogens (Stockman and Harrar 1957) increases with increase in relative humidity.

C. rolfsii, however, requires low humidity for germination (Watkins 1958); because of low

humidities wrinkling and cracking of the sclerotium cortex occur (Boswell 1958). Fungi whose spores are enhanced by low humidity are known to grow better under such conditions (Cochrane 1958). Hence rot on corms here was highest at lower relative humidities, especially in *C. esculenta*. In *X. sagittifolium* it appeared the rot was enhanced with increases in humidity. Records have shown that rate of water loss in this species is higher than that of *C. esculenta* (Table 9). Thus, at lower humidities this rate will increase and create a microclimate of high relative humidity of the corm surface, which is adverse to the mycelial growth and pathogenesis of *C. rolfsii*. Moreover, with increased desiccation of the corm, the inner flesh hardens and checks the pathogen, which prefers more succulent plant tissues. At a higher humidity, on the other hand, this loss of water within the corm tissues and its accumulation on the surface are reduced; therefore the conditions favour the growth of the mycelium and increased rot.

Our observations have been confirmed by results (Table 10) from a comparison of the effects of free moisture on rot development in the two species. These findings are buttressed by a study on the effects of various indigenous methods of storage in corm rot (Table 11). Corm rot in *X. sagittifolium* is reduced when the corms are stored on raised rafters and left uncovered. This technique creates an unfavourable microclimate of high humidity on the corms' surface, and the freer aeration speeds subsequent hardening of the corms' flesh against invasion. In contrast, *C. esculenta* suffers least damage from *C. rolfsii* when stored in pits or baskets, ashed, and covered with pieces of fresh plantain trunk because this method maintains a higher humidity. How ashing affects corm rot is not known, but it reduces attack from termites.

Though low temperatures limit rot development in the corms, cold storage of yam has been shown to reduce the quality of the produce (Coursey 1968a). Its effect on the cocoyam is not known. Moreover its use may lead to high expenditures.

Table 10. Mean diameter of rot induced by *C. rolfsii* on corms of two varieties of cocoyam under three moisture conditions (uninoculated controls did not develop rot).[a]

Condition	Diameter of lesions (mm)	
	X. sagittifolium	*C. esculenta*
Dry	29.33	29.00
Moist	32.66	45.00
Wet	45.00	21.66

[a]Coefficient of variation is 7%; LSD (0.01) is 1.73.

Table 11. Effects of storage methods on mean diameter (mm) of corm rot induced by *C. rolfsii* on two varieties of cocoyam.[a]

Storage method	Diameter of rot (mm)	
	X. sagittifolium	*C. esculenta*
Barn floor	18.25	24.00
Raised rafter	13.50	18.00
Soil pit	24.00	16.75
Basket	27.50	16.25
Uncovered	13.00	21.25
Covered	25.25	20.00
Ashed/uncovered	24.75	21.25
Ashed/covered	20.25	19.75
Control	0.00	0.00

[a]LSD (0.05) is 1.29; LSD (0.01) is 1.69.

Local people prolong shelf-life of cocoyam by storage in pits or rafters as reported in different countries (Gollifer and Booth 1973b). It is probable that feasible storage methods can be created by management of the humidity of the environment.

CONCLUSION

C. rolfsii disease is well known in Nigeria as an important contributor to yield losses and storage deterioration in cocoyam. Workers may control it in the field and optimize the yield of corms by:

- Plowing the field thoroughly to expose the pathogen to solar radiation early in the season to maximize drying;
- Mulching soon after planting with slowly decomposing materials that increase the C:N ratio in the soil and reduce *C. rolfsii* buildup by increasing the population of other better competitors for the limited nitrogen available;
- Avoiding fields that have been previously monocropped with cassava and cocoyam, leaving such fields to nonhosts such as grasses;
- Hilling and hoe-weeding and, possibly, using preemergence herbicide that would reduce labour costs and would not significantly stimulate the disease;
- Planting deep to reduce field corm rot;
- Using tolerant and high-yielding varieties; the economic threshold for most of the cultivars is severity class 3.

In addition, they may minimize storage rot of corm by:

- Avoiding bruising the corms during harvest;

- Allowing the remains of the petioles to dry well before removal and storage to avoid opening of wounds;
- Removing corms harvested from fields infested with *C. rolfsii*, especially corms showing signs of the mycelial infestation before storing any corms;
- Storing *X. sagittifolium* on uncovered, raised rafters and *C. esculenta* in soil pits or baskets covered with fresh pieces of plantain trunks. The inside of the pits or baskets may be lined with ash to exclude termite damage.

COCOYAM FARMING SYSTEMS IN NIGERIA

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Cocoyam cultivation in the eastern and western regions of Nigeria is described. Cocoyam is generally grown on upland, well drained, fertile soils. Mixed cropping with maize and yam is common. Cocoyam appears early in the yearly crop rotation and is often followed by cassava. Labour utilization for cocoyam is estimated to be lower than that for cassava for cultivation as well as for preparation. Economically it is an attractive crop.

Description de la culture du taro à l'Est et à l'Ouest du Nigeria. Dans ces régions, on cultive généralement le taro en haute terre, sur des sols fertiles, bien drainés, en association avec le maïs. Hâtive, cette plante vient en tête d'assolement, souvent suivie par le manioc. Elle est moins exigeante que ce dernier, en termes de travaux agricoles, y compris la préparation du sol. Et elle est également intéressante sur le plan de la rentabilité.

Cocoyam is a poorly documented crop. Basic information about its role within West African farming systems is scarce. Nigeria is the largest producer of this crop in the world with 40% of the total production (Onwueme 1978c), but cocoyam ranks third among root crops in the country, following yam and cassava (Federal Office of Statistics). In other countries, cocoyam is more important; for example, in Cameroon, cocoyam is the second most important crop, only exceeded by cassava (Lyonga 1980), and Karikari (1971a) maintains that cocoyam is the most important root crop in Ghana. Also in Gabon, cocoyam belongs to the most important food staples.

Researchers who are developing improved cocoyam varieties and improved production practices need basic information about the present cocoyam cultivation methods.

The purpose of this paper is to present information about the manner in which cocoyam is at present planted, cultivated, harvested, and utilized in Nigeria. Specific questions are: What are the planting practices? How do the farmers use the different varieties? With what other crops is cocoyam associated? What is the labour utilization for cocoyam? What are the harvest and storage practices? And which marketing and processing practices are important?

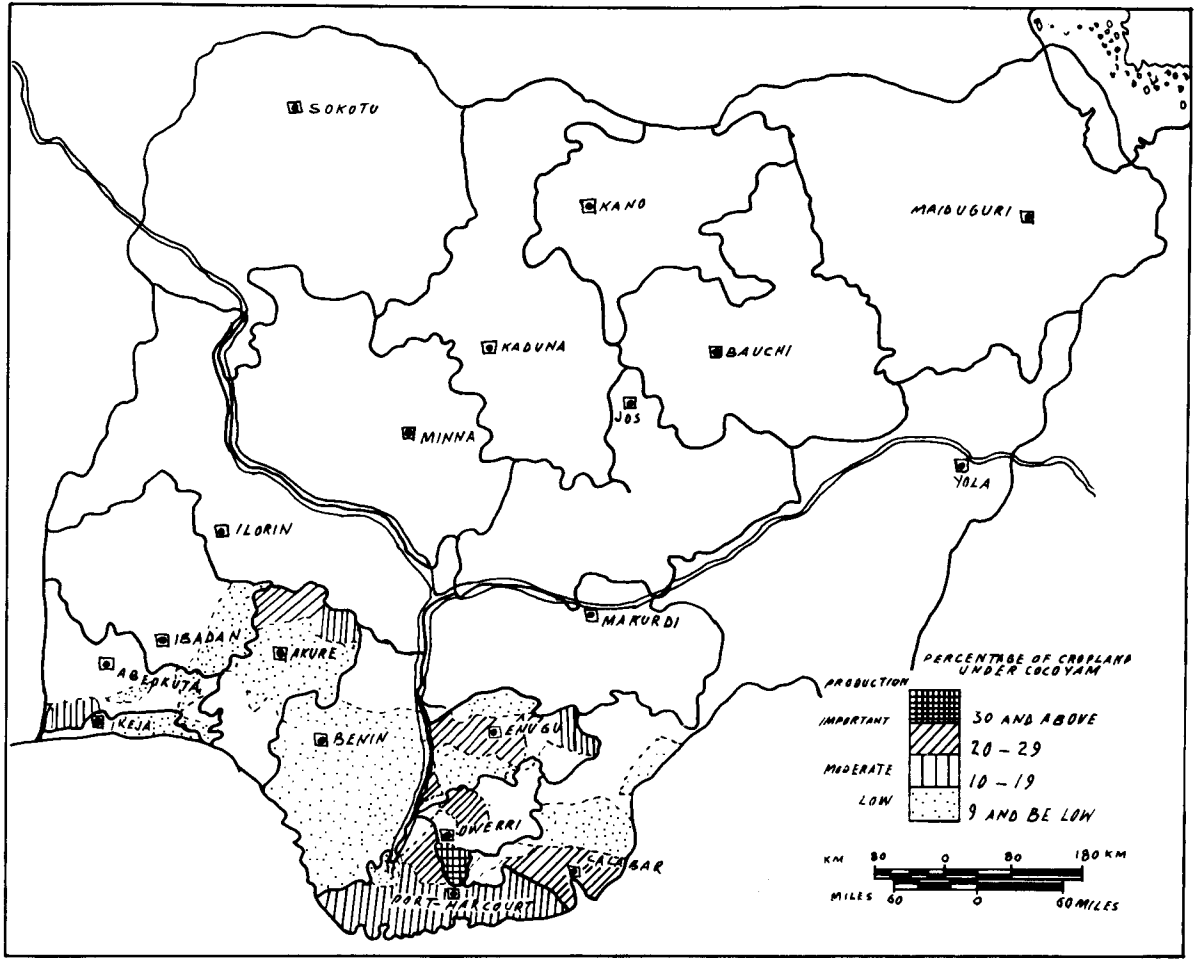
METHOD

Fig. 1 shows the areas in Nigeria where cocoyam is a main food staple. Three of these areas were selected for a short description survey. As cocoyam is predominantly grown in the eastern part of Nigeria, the two highest producing states, Anambra and Imo, were selected as well as Ondo State, the highest producing state west of the Niger. In each state three or four villages where cocoyam was considered to be an important food staple were selected upon recommendation of local Ministry of Agriculture and Natural Resources (MANR) officers. In each of the villages, individuals in six or seven households were interviewed. In most of these it was the women who grew cocoyam.

The sampling method was aimed at providing general information about the systems in which cocoyams are grown rather than at testing specific hypotheses. The selection method of villages and households might be biased because of accessibility of villages, willingness of farmers to cooperate, or personal preferences of local agricultural officers. However, the results provide a sufficiently general picture of cocoyam production in each of the three states so that relevance of the results can be claimed.

Yield figures were not taken. Several sources (Phillips 1976; Olayide 1972; Onwueme 1978c; Federal Office of Statistics 1979) indicate that the average yield for cocoyam in the surveyed area amounts to about 6000 kg/ha.

Farming-system surveys increasingly follow more-or-less standard methods. Delgado (1979), Norman et al. (1979), and Atayi et al. (1980) all arrange their data under similar headings. The observations are grouped around the different pro-



SOURCE: AN AGRICULTURAL ATLAS OF NIGERIA
S.A. AGBOOLA, OXFORD UNIVERSITY PRESS, 1979

Fig. 1. *Cocoyam cultivation in Nigeria.*

Table 1. Average number of fields in use and in fallow by state.

State	Fields in use	Fields in fallow	% farmers with compound	Fields excluding compounds	Land-use factor[a]
Ondo	3.6	3.0	33	3.3	2.1
Imo	4.0	1.0	95	3.0	1.3
Anambra	5.0	1.0	100	4.0	1.3

[a]Allan's land-use factor, L is (C + F)/C where C is the cropping period and F is the fallow period.

duction factors within a farming system, such as land, labour (labour calendar, availability, utilization), capital (paid and nonpaid inputs), cultivation practices (intercropping, rotation), and utilization methods (household processing and marketing).

This survey was conducted along the same lines. However, the questioning was kept short (about 45 min per interview) and focused only on the cocoyam component of the farming system.

RESULTS

Table 1 shows the average number of fields in use and in fallow by state. It also shows the percentage of farmers in each state that grow cocoyam in a compound. The average length of cultivation and fallow in Ondo are respectively 6 and 5 years. For Imo and Anambra the figures are 3 and 1 years.

Assuming that the average size of fields in use and fallow is the same, we derived the land use factors (Allan 1965). From questions concerning the history and future of the cocoyam plot, we also derived the average cropping–fallow rotation pattern.

Particularly in Imo and Anambra, cocoyam is grown on soils that are intensively used. The relatively long cropping period in Ondo might be associated with the relative importance of the cocoa culture in this state.

The majority of the farmers (91%) grow cocoyam on upland or compound fields. It seems that Nigerian farmers in the locations sampled do not utilize hydromorphic soils (low land) for cocoyam cultivation. Farmers generally mentioned a high number of alternative crops (food crops as well as tree crops) that could be grown where cocoyam is at present grown. Their answers confirm that cocoyams are being grown in well-drained, fertile, upland soils.

Table 2. Responsibility for cocoyam growing by sex.

	Male	Female	Both
Ondo	6	8	8
Imo	0	19	2
Anambra	0	16	5

In those locations where there are no serious nematodes or root-rot problems, cocoyam can be grown without interruption for a number of years. This practice is limited to the Ondo area where the average number of years during which cocoyam is grown on the same plot without interruption amounts to 3 years; in Imo and Anambra the majority of farmers apply rotation. On the same plot they grow cocoyam once every 2 or, more often, every 3 years. Only 40% of the farmers in Ondo apply this kind of rotation. In particular, farmers who intercrop cocoyam with cocoa report a long duration of continuous cocoyam cropping (average 5.5 years).

Cocoyam is mostly grown by women (Table 2). In Imo and Anambra states, it is almost exclusively cultivated by women.

Together with land, labour is the farmers' main resource. Measurement of actual labour utilization data is time-consuming and tedious work. A cheaper way to measure labour utilization is to ask farmers to compare labour use for cocoyam with labour use for other — more popular — crops for which labour utilization data are fairly well known. A preliminary survey indicated that cassava and maize could serve as such crops. The farmers were asked to rank maize, cassava, and cocoyam according to their labour requirements per activity (Table 3).

Cocoyam required less labour than did cassava for land preparation, weeding, and harvesting. Only for planting was it more labour-intensive than cassava. We updated earlier well-documented estimates for cassava and maize (Knipscheer 1980) based on our findings, using the algebraic formula (Table 4): U cocoyam = U maize + (S cocoyam/S cassava) (U cassava–U maize) where U = labour utilization crop (Table 4, first two columns) and S = adjusted score (Table 3).

The survey showed that in 1979 the average farmer hired about 10% of the labour that was used

Table 3. Comparison of cocoyam, maize, and cassava according to labour requirements.

	Most	Least	Crop score[a]	Adjusted score
Land preparation				
Maize	7	49	-42	0
Cocoyam	24	10	+14	56
Cassava	35	37	+28	70
Planting				
Maize	–	55	-55	0
Cocoyam	40	4	+36	91
Cassava	26	7	+19	74
Weeding				
Maize	5	32	-27	0
Cocoyam	30	28	+2	24
Cassava	28	3	+25	52
Harvesting				
Maize	3	47	-44	0
Cocoyam	29	17	+12	56
Cassava	34	1	+33	77

[a]Most = +1 point; least = -1 point.
[b]Crop score minus maize score.

for cocoyam. This amounted to about 14 mandays/ha of which 11 mandays/ha were utilized for land preparation and planting and 3 mandays/ha for weeding. The implication is that of the 128 days/ha that farmers invest their own labour, about 40 are spent on land preparation and planting, 33 on weeding, and 55 on harvesting. In percentages this amounts to respectively, 31, 26, and 43 of the total labour for cocoyam.

Separately the farmers were asked how many days they spent per activity on their own plots. The average distribution of their own labour over the activities was 26% for land preparation and planting, 28% for weeding, and 46% for harvesting.

The labour percentages per activity derived from the comparison with maize and cassava and those derived from the farmers' own labour expenditure are within a margin of only five percentage points. These figures support the results of the estimation method that we followed (i.e., by crop comparison).

Among the three states, farmers in Imo spend the most time on planting, whereas farmers in Ondo spend the most time on weeding. These findings are consistent with the intensive mixed cropping system that is followed in Imo and the wider spacing reported from Ondo.

In addition to the cultivation technique, farmers were asked to rank cassava and cocoyam according to transport and preparation (processing) requirements. For transport, a small majority (54%) of farmers judged cassava a more time-consuming crop than cocoyam. In the case of food preparation, the vast majority (88%) find cassava preparation more difficult than cocoyam preparation.

The conclusion is that cocoyam needs about 16% less field labour than does cassava, and it is a less time- and labour-consuming crop for cultivation as well as for food preparation.

Farmers use corms, cormels, or headsets as planting material. Planting material is stored in a shady place and covered with (palm) leaves. Generally presprouted headsets and cormels are selected for planting. If cocoyam is replanted on the same field, as is common in Ondo, the stem is trimmed and put in the old planting hole. This practice can be repeated until the yield or the quality of the crop declines (see also Karikari 1971a).

The choice of types and varieties partly depends on the region. In Imo and Anambra, all farmers grow both *Colocasia* ("old" cocoyam, taro) and *Xanthosoma* ("new" cocoyam, tannia). Without exceptions, they grow the "red" and the "white" varieties of both *Colocasia* and *Xanthosoma*.

In Ondo, however, *Xanthosoma* is preferred. Only 50% of the farmers also used *Colocasia*. The *Xanthosoma* red variety is generally later maturing than the white variety and may be less scratchy. Farmers generally eat the cormels of the red variety of *Colocasia*, but the central corm of the white *Colocasia* variety is preferred.

As almost all (three or four) varieties are grown mixed on the same plot, differences in planting practices between varieties could not be determined.

In nearly all cases, planting is done at the beginning of the rainy season. However, farmers in Ondo generally report earlier planting dates than do farmers in Imo and Anambra. The first plant mainly during March and April, whereas the others plant during April and May. Replanting is only reported from Ondo, and its necessity may be due to the earlier planting date. Indeed, the problem of drought is mentioned far more often in Ondo (67%) than in Imo and Anambra (12%).

Also the spacing between the plants varies by region. From the reported distances between rows and between plants within rows, the average m^2/plant was calculated as the measure of spacing. In Ondo the spacing was 0.51 m^2, Imo 0.32 m^2, and in Anambra 0.39 m^2.

The reported spacings are much closer than those mentioned by Phillips (0.81 – 1.8 m^2). These spacings are barely wider than the spacing (0.36 m^2) recommended by Onwueme.

Farmers that do intercrop their cocoyam with trees report an average spacing of 0.45 m^2. The spacing between tree intercropping and nontree intercropping probably reflects cocoyam planted in clusters between scattered trees. In that case the relevant spacing is not only the one within the cluster (probably the one that is reported) but also the one between clusters (which is still unknown).

Planting of cocoyam generally is done on low mounds (56%), ridges (32%), and on the flat (53%). (More than one answer was allowed.) Only 1 of the 66 farmers surveyed planted cocoyam on high mounds. This confirms the impression that cocoyam in Nigeria is mainly grown on upland.

Two important elements of cultural practices are intercropping and rotation. Intercropping with other food crops is most common in Imo and Anambra where 76% of the farmers practice intercropping. In Ondo this percentage is much lower (51%). We recall the importance of compound cocoyam farming in Imo and Anambra. Among the farmers who intercrop, maize (85%), yam (50%), okra (33%), cassava (33%), and pepper (28%) are the crops that are most often associated with cocoyam.

Analyses by state show that cocoyam – maize is the crop mixture typical for Ondo, cocoyam – yam – maize typical for Anambra, and cocoyam – yam – maize – cassava typical for Imo.

Associations with tree crops are common in all three states. However, intercropping with cocoa occurs only in Ondo. Intercropping with kola and citrus is popular in all three states.

Cocoyam fits well into these crop and tree mixtures because it is more shade-tolerant than most crops. It will produce a reasonable yield when grown under shade during parts or all of its growth cycle.

Rotation is the periodic interruption of the cultivation of a crop. Changes in soil fertility, populations of nematodes, and soil pathogens often force the farmers into rotating their crops. The cropping – fallow rotation is longest in Ondo and relatively short in Imo and Anambra (if not nil in compound farming). Also the cocoyam cultivation without interruption on the same plots is longer in Ondo than in Imo and Anambra. The intercropping with cocoa trees, which allows few other crops but the shade-tolerant cocoyam, may explain this relatively long duration.

In Imo and Anambra, however, cocoyam is seldomly cultivated for 2 years in a row, although at present few nematode problems for cocoyam are known. To establish cocoyam's place in the rotation of crops, we asked farmers to name the two most important crops they grew before and after cocoyam (Table 5).

Just as cocoyam is preferably intercropped with maize, yam, and cassava, these crops are dominant in the yearly rotation system (Table 5). Further analysis shows that yam – cocoyam mixtures often are preceded by yam cultivation (19 of 23 farmers). Moreover, a good percentage of farmers who grow yam first will again grow it on the same (probably compound) plot. As a matter of fact, one-third of the farmers that were surveyed in Imo and Anambra indicated that they were growing yam on the same plot at least 3 years without interruption and that in

Table 4. Labour utilization (mandays/ha) for maize, cassava, and cocoyam by activity.

	Maize (manday/ha)	Cassava (manday/ha)	Cocoyam (manday/ha)
Land preparation	24	40	37
Planting	10	13	14
Weeding[a]	25	45	36
Harvesting	16	70	55

[a]Generally two weedings for cocoyam.

Table 5. Frequency of crops before and after cocoyam (all three states).

	Before	After
Yam	31	30
Maize	23	24
Cassava	7	20
Pepper	9	6
Okra	12	4
Vegetables	7	1
Others	4	8
None	7	6

at least 1 year the yam would be intercropped with cocoyam.

Cocoyam preferably is grown before cassava. This fact confirms the notion that cassava generally dominates the crop mixtures at the end of the cropping period, when the soil fertility has decreased to minimum levels and the debris remaining after the harvest does not have to be cleared. The rotation patterns confirm earlier findings of compound farm rotations in east Nigeria and rudimentary sedentary cultivation rotation in western Nigeria (Okigbo 1978).

The yam–cocoyam rotation partly explains why households in Ondo plant, harvest, and eat cocoyam earlier than they do in Imo and Anambra. Farmers in Ondo plant their yams in the dry season; this means they must clear and prepare their land at the end of the rains. If the yam is following cocoyam, they must clear the cocoyam from the land before December. They must eat it soon after because cocoyam does not store for very long. In contrast, most farmers in the East plant yams at the beginning of the rains, and there is no need to remove the previous crop until February–March. Because they plant yams with the rains, cocoyams would be planted later. Yams are regarded as more important and must be finished before the farmers can turn to other crops. In Ondo, where the yams are planted in the dry season, the farmers can begin to plant cocoyam as soon as the rains are steady.

HARVEST AND STORAGE

In Nigeria, cocoyam is generally harvested 9–10 months after the planting. According to most farmers, cocoyam has to stay in the ground at least 7 months. Harvesting is done from November until March–April (Fig. 2). Farmers in Ondo tend to harvest earlier than do those in Imo and Anambra. Most farmers (60%) harvest in bits. Only in Anambra a relatively larger number of farmers harvest at once, possibly because of the larger quantity of cocoyam that is sold on the market in this state (Table 6).

Table 6 shows the importance of cocoyam as a cash crop in the eastern part of Nigeria. Half of the farmers interviewed in Imo and Anambra sell half or more of their cocoyam. In Ondo, only 25% of the farmers grow cocoyam as a cash crop.

An important aspect of the cultivation of cocoyam is that it is harvested just before and during the "hungry" season. This is the period of relative food shortages associated with the time between the exhaustion of food stocks from the previous year and the harvest of the new crops (maize, yam, rice) (Nwana et al. 1979) (Fig. 3).

Forty percent of the farmers (mainly those in the East) reported that they never leave any part of the cocoyam production in the ground but that they harvest it all during the same season. Only in Ondo do farmers commonly leave part of the cocoyam crop unharvested.

A surprising 92% of the farmers indicated that they increased the size of their cocoyam plot during the last 5 years. Many mentioned "increasing responsibilities" as the reason. Seventy percent said it would be easy to increase cocoyam production by increasing the area planted. None of the farmers opted for a greater number of plants on the same plot (i.e., more intensive land use) as a means for potential production increase.

Little is known about the storage of cocoyam corms and cormels. The predominance of household consumption and the possibility of leaving cocoyam in the ground mean that elaborate storage facilities are not required. Aboveground, cocoyams are stored in heaps covered with leaves in a shady place. Sometimes barns are constructed. Also storage in the house (in baskets) is common. Another

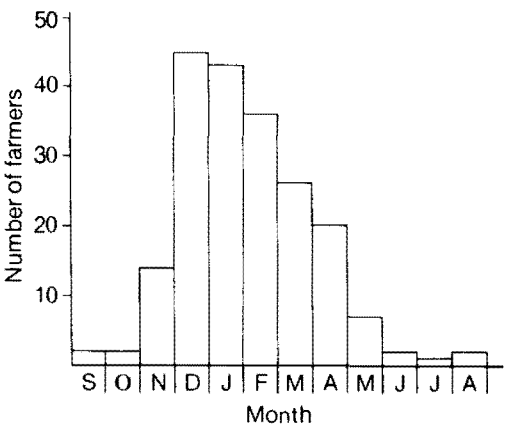


Fig. 2. *Frequency of harvest activity for cocoyam by month.*

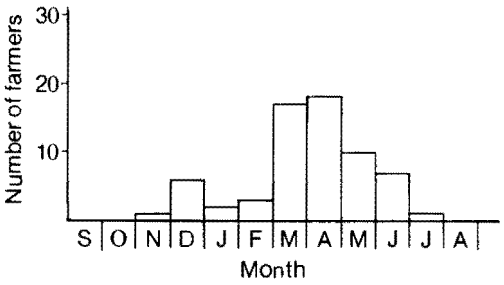


Fig. 3. *Distribution of farmers by month during which most cocoyam is consumed.*

method is the digging of pits. Although Nwana et al. (1979) observed that pit storage in Anambra State had been "almost entirely" abandoned, it is still used by many farmers that participated in this survey. In all these cases no storage problems (diseases, rotting, or pests) were reported (Table 7).

The most common storage method in Ondo is in barns/huts (67% of the farmers), in Imo in baskets in the house (43% of the farmers), and in Anambra in pits (86% of the farmers).

Losses during storage may amount to 30–50%. The farmers who were interviewed, however, generally (83%) reported no storage problems. Specific problems mentioned are pests, rotting, diseases, and sun. The fact that so few complained of problems underlines the general reliability of the methods; of the 11 complaints, 7 (64%) were for storage in the field, whereas only 3 (12%) were for storage in huts or barns, and 1 (9%) was for storage in the house. Storage in pits proved technically to be a superior method (no complaints). In association with storage, the problem of transport of cocoyam (from field to storage place) is often mentioned (29% of the farmers).

Leaves can be stored for a few days when fresh, and for a few weeks when dried. The drying of leaves is much more common in Imo and Anambra than in western Nigeria.

UTILIZATION

Cocoyam corms, cormels, and leaves are eaten. Agreement exists among the farmers that the corms, cormels are economically more important than are the leaves. Cocoyam leaves, therefore, can be characterized as a by-product. They are mainly used for soup (45%) or for wrapping (6%) or for both purposes (38%). Only 10% of the farmers surveyed (all from Ondo) do not use the leaves at all.

Cocoyam corms and cormels can be prepared in different ways. Pounding (pure or mixed with yam) is the most popular method (50–60% of cocoyam production), but boiled cocoyam (10–20%) and roasted cocoyam (10%) are also popular uses. Roasting is not common in Ondo.

Both *Xanthosoma* and *Colocasia* contain an irritant that causes scratchiness in the mouth and throat if they are eaten raw or undercooked. Generally, it is accepted that the irritant is calcium oxalate crystals, although there is now some evidence that these crystals are not, or are not the only factor, involved. Whatever the factor, it is destroyed by cooking. The quantity of irritant varies among varieties. The "sweet" varieties can be boiled and eaten just like yam, whereas the scratchy ones must be boiled for a very long time. As a general rule, *Xanthosoma* contains less irritant and requires less cooking than does *Colocasia*. The red variety of *Xanthosoma* is said to be particularly low in irritant and, therefore, most popular for roasting.

Farmers distinguish two white *Xanthosoma* varieties, one "soft" and one "hard." The hard one is very sweet and generally boiled or roasted. The other variety is preferred for pounding (with or without yam), as its softness makes the pounding easier. *Colocasia* is said to be mostly soft and, therefore, generally is pounded. To improve the palatability of *Colocasia*, households sometimes mix it with the hard but sweet *Xanthosoma* variety.

Porridge (10–20%) is also a popular form of food preparation. Grating (5% of total cocoyam production) is mainly practiced in Anambra, whereas the processing of cocoyam into flour is very uncommon in east Nigeria and only rarely seen in west Nigeria.

Prices of fresh cocoyam are generally higher than are those for fresh cassava — about twice as high in east Nigeria (Lagemann 1978; Ministry of Finance and Economics Development 1978) as well as in Cameroon (Kamajou et al.). The price difference might be based partly on the difference in nutritional value of cassava and cocoyam, partly on the labour requirement for food preparation, and partly on taste differences between the two crops.

The digestible protein content of cassava is 1%

Table 6. Distribution of farmers (% per state) by cocoyam sales.

	Sales			
	None	Little	Half	Most
Ondo	8	67	17	8
Imo	14	38	34	14
Anambra	–	52	29	19

Table 7. Distribution (%) of farmers by storage method.

	Storage method				
	Barn/ hut	Field/ farm	House	Pit	NP[a]
Ondo	24	8	3	–	1
Imo	9	9	14	–	–
Anambra	3	–	–	28	1

[a]NP = no preference.

Table 8. Farmers' perceptions of the taste of cocoyam compared with other food staples.

	Taste compared with cocoyam			
	Better (%)	Equal (%)	Worse (%)	DK[a] (%)
Yam (yellow)	89	0	11	0
Yam (white)	89	2	9	0
Cassava (boiled)	2	3	94	1
Cassava (gari)	15	32	53	0
Rice	44	26	29	1
Maize	23	29	48	0

[a]DK = don't know.

(on dry-weight basis) compared with 5–5.6% for *Xanthosoma* and *Colocasia*. For cocoyam leaves, the digestible protein varies from 12 to 15.5% (of dry matter). The calorie values are about the same for cassava, cocoyam, and yam; they are, respectively, 376–391, 376–383, and 373–391 cal/100 g (Oyenuga 1968).

Table 8 shows the farmers' taste preferences in the different food staples. The place of cocoyam in the table (behind yam, but before maize and cassava) seems to refute the label of "a poor man's crop." Cocoyam is grown not only because of its low labour input and its time of harvest (before and during the "hungry season"), but also because of its taste.

CONCLUSIONS

The conclusions of this study are:

- Planting dates for cocoyam in Nigeria vary from March–April to April–May and seem to be dependent on the planting and the harvest dates for yam; thus, the cocoyam farming system is a component of a larger yam-based farming system; this finding is confirmed by the intercropping and rotation patterns that were reported;
- Different cultivation methods for different varieties of cocoyam are not distinguished; all varieties are cultivated on well-drained, fertile, upland soils; the choice of variety seems largely dependent on the method of food preparation and qualities, i.e., whether the variety is "hard," "soft," "scratchy," or "sweet";
- Sole crop farming of cocoyam is rare; mixed cropping with maize is the typical, although also the yam–cocoyam–maize association is very common. Intercropping with trees (kola, citrus) is also often practiced;
- Cocoyam is a less labour-intensive crop than is cassava for field work, and labour utilization is estimated to be about 142 mandays/ha;
- The most important storage methods are a shady place in the field, in huts or barns, in the houses, and in pits; these methods protect the cocoyam against pests, diseases, and the sun;
- A large number of households (40% of the farmers surveyed) grow cocoyam as a cash crop, selling at least half of the yearly production; the cocoyam is considered to be less palatable than is yam (white or yellow) but better than maize and cassava; pounding is the most common form of food preparation;
- The vast majority of the farmers (92%) have increased their cocoyam production during the last years; this shift indicates growing popularity of this crop.

It seems, therefore, that cocoyam no longer is a "poor man's crop" but rather a "crop with promising economic value" (National Academy of Sciences 1975). In Nigeria, farmers are increasing their cocoyam production, as the crop is perceived to be less labour-intensive than cassava. It can be easily cultivated in association with other crops, food crops as well as tree crops. Its nutritional value, its taste, its labour requirements for food preparation, and its market value give the crop an economic edge over cassava.

The implications of this study for cocoyam breeding are that cocoyam deserves further attention because of its economic value and potential; characteristics such as "hard" versus "soft" and "scratchy" versus "sweet" are important and should be studied more intensively; new varieties should maintain the current usefulness of cocoyam as intercrop; because the period of cocoyam consumption is prolonged when planting is done early in the season (as in Ondo), cocoyam varieties with better drought resistance should be sought.

YIELD AND NITROGEN UPTAKE BY COCOYAM AS AFFECTED BY NITROGEN APPLICATION AND SPACING

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Three amounts of N (0, 40, and 80 kg/ha) were tested on cocoyam, *Colocasia* spp. planted at 80, 60, and 40 × 100 cm at Umudike, Nigeria. Basal dressings of P, K, and Mg were given at 40, 75, and 20 kg/ha respectively. Averaged over all population means, application of N at 40 kg/ha increased yields of corms and cormels by 4.47 t/ha ($P = 0.05$). The largest yield increase of 8.99 t/ha due to N dressing was achieved with 40 kg/ha at a spacing of 100 × 60 cm. But when averaged over all N rates, the mean yields of corms and cormels with respect to the various spacings were not significantly different even though plant heights increased with population density. Observed significant increase in yield due to N was related to an extra 15.3 kg/ha taken up in the tuber when 40 kg/ha was given. This was equivalent to an apparent recovery of 38.3% of the applied N. Tuber yields were more related to the number of cormels than of corms at harvest.

Effets de 3 dosages de N (0, 40 et 80 kg/ha) sur des taros cultivés en plantation à Umudike, Nigeria, espacés de 80, 60 et 40 cm × 100 cm. Un traitement basal de P, K et Mg a été appliqué en quantités respectives de 40, 75 et 20 kg/ha. La production de tubercules et de bulbilles pour l'ensemble des peuplements a donné une augmentation moyenne de 4,47 t/ha avec la dosage de 40 kg/ha. Le rendement optimal de 8,99 t/ha a été obtenu avec le traitement de 40 kg/ha sur des plantes espacées de 60 cm × 100 cm. Cependant, la production moyenne de tubercules et de bulbilles pour l'ensemble des plantes, quel que soit l'espacement ou le dosage d'engrais, a été sensiblement identique sauf en ce qui concerne la hauteur des plantes qui a été plus élevée dans les peuplements à forte densité. L'accroissement du rendement chez les plantes amendées avec un dosage de 40 kg/ha de N s'est traduit par une augmentation de poids des tubercules de l'ordre de 15,3 kg/ha, ce qui signifie la récupération apparente de 38,3% de la quantité de N. La production de racines intéresse davantage le nombre de bulbilles que de tubercules.

The use of optimum spacing is necessary for the maximum exploitation of the factors essential for crop growth. Such exploitation can be accomplished when population density of a crop exercises maximum pressure on all production factors, such as solar radiation, soil nutrients, and water.

We believed, therefore, that it was necessary to assess the effects of spacing and nitrogen fertilizer on the yield and N uptake by one of our cocoyam cultivars locally called Ede ofe grown under the upland soil conditions at Umudike, Nigeria.

METHODS

Our experiment was conducted on sandy-loam soil derived from sandstone at Umudike, Nigeria, from May 1979 to February 1980. Some of the soil characteristics were pH 5.3, sand 76.4%, clay 6.8%, silt 16.8%, organic carbon 1.35%, total N 0.074%, available P (Bray P-1) 8.0; and exchangeable cations: Ca 1.87, Mg 1.25, K 0.24, and Na 0.06 me/100 g.

The experimental design was a randomized complete block with three replications. Four spacings, 100 × 80; 100 × 60; 100 × 40; and 100 × 30 cm (corresponding to 12 500; 16 666; 25 000; 33 333 plants/ha) were compared at three nitrogen rates (0, 40, and 80 kg/ha).

Basal dressings of 40, 75, and 20 kg/ha of P, K, and Mg, respectively, were given. Plant height was measured at 4.5 months after the planting, and crops were harvested after 8.5 months.

Soil pH was determined on a 1 : 2.5 soil, water ratio and texture by the hydrometer method. Organic carbon was by Walkley and Black's procedure, and available P was as described by Bray and Kurtz. Total exchangeable cations were leached with neutral normal ammonium acetate. Total N in corms and cormels and in soil was measured by the Kjeldahl method.

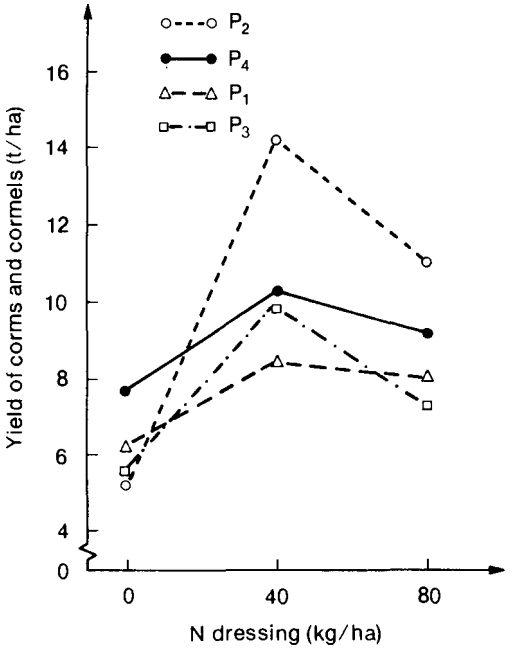

Fig. 1. *Yield of corms and cormels as influenced by spacing and N dressing.*

RESULTS AND DISCUSSION

YIELD OF CORMS AND CORMELS

Fig. 1 shows that, at all the population densities tested, the highest yields of corms and cormels were obtained with an application of 40 kg N/ha. Averaged over all N rates, the application of 40 kg N/ha increased yield of corms and cormels by 4.47 t/ha equivalent to 112 kg corm and cormel per kg N used (P = 0.05). At N applications of 80 kg/ha, yields were 2.69 t/ha larger than those from plots without N. The reason for this drop in yield is not clear but may be due to increased disease or lodging.

However, several multilevel N tests are necessary before the relationship between yield and N dressing can be described accurately. In our experiment only three rates of N were tested (0, 40, and 80 kg/ha). These are too few to show whether the corm/cormel yield N response curve is best fitted by a smooth curve or by two intersecting straight lines.

Of the various spacings we compared, 100 × 60 cm gave the largest mean yield (10.1 t/ha). The difference of 2.55 t/ha between the yield at this spacing and yield at the 100 × 80 cm spacing, which gave the least mean yield (7.57 t/ha) was not significant. However, the increased yield at 100 × 60 cm is in good agreement with the results of Arene and Okpala who obtained lowest rate of incidence of *Corticium rolfsii* in *C. esculenta* at a spacing of 60 × 100 cm as against high rates in spacings of 80 × 100 and 100 × 100 cm for shallow planting. They also obtained their best yield at 60 × 100 cm spacings.

N CONCENTRATION, UPTAKE, AND RELATIONSHIP WITH YIELD

Percentage of N in corms and cormels ranged from 1.39 to 2.1 (similar in crude protein to cereals) and was slightly higher (1.9%) at 80 kg N/ha than at 40 kg N/ha and in controls (1.6%). At 80 kg N/ha applications, the largest N uptake (45.9 kg/ha) occurred even though the overall yield was

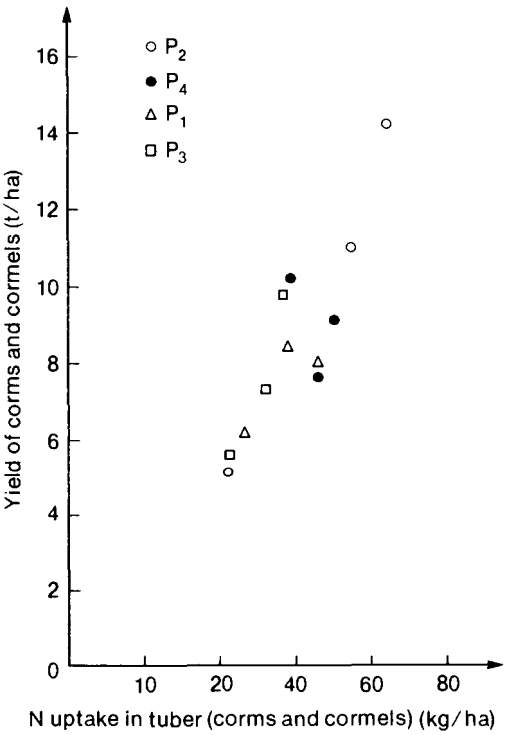

Fig. 2. *Relationship between yield and N uptake in corms and cormels of* Colocasia *sp.*

Table 1. Number of corms and cormels in relation to spacing and nitrogen (kg/ha) application.

Spacing (cm)	Corms			Cormels		
	N_0	N_{40}	N_{80}	N_0	N_{40}	N_{80}
100 × 80	33	27	29	212	223	241
100 × 60	18	52	40	172	314	421
100 × 40	34	37	40	181	369	327
100 × 30	66	42	38	289	261	254

Table 2. Effect of spacing and N application on height (cm) of *Colocasia*.

Spacing (cm)	*Colocasia* height (cm)			
	0 kg N/ha	40 kg N/ha	80 kg N/ha	Mean
100 × 80	55.8	78.8	82.5	70.3
100 × 60	60.5	81.0	72.6	71.4
100 × 40	66.0	82.5	70.8	73.1
100 × 30	78.3	80.0	77.1	81.4

1.78 t/ha less than that at 40 kg N/ha. Mean uptake of N by cocoyam with 40 kg N/ha dressing was 44.4 kg/ha, 15.3 kg/ha more than that when no N was given. This amounted to a net apparent recovery of 38.3 and 21% for application of 40 and 80 kg N/ha, respectively, in the corms and cormels. It is noteworthy that the treatment that gave the highest apparent recovery of N also produced the highest yield of corms and cormels (40 kg N/ha). Similarly for the population densities, N uptake was largest at a spacing of 100 × 60 cm (47 kg N/ha), which gave the largest yield.

Fig. 2 shows the relationship between yield of corms and cormels, and the N uptake of the tuber can be expressed by a linear model: $Y^1 = 1.91598 + 0.16725 \times Nc$ where Y^1 = yield of corms and cormels and Nc = uptake of N in corms and cormels (kg/ha).

The correlation coefficient (r) was 0.8706 and regression of yield of corms and cormels on N uptake accounted for 75.9% of the variance.

Number of Corms and Cormels and Relationship with Yield

Table 1 gives the number of corms and cormels as influenced by spacing and N dressing. Averaged over all spacings, N application had an increasing effect on the number of cormels but not on the number of corms.

The number of corms was only 14% of the total yield, 86% being accounted for by cormels. Cocoyam grown at a spacing of 100 × 60 cm had the largest number of cormels. In other words, the yield increments were largely attributable to the increase of cormels. Regression analysis of total yield showed that the cormels accounted for 43.6% of the variance, whereas the corms accounted for only 21.9%.

Plant Height, Flowering, and Deficiency Symptoms

Plant height measurements 4.5 months after planting showed that *Colocasia* spp. grew taller as intra-row spacing decreased. For example, at a spacing of 100 × 80 cm, plants grew to a mean of 70.3 cm, and at 100 × 30 cm, to 81.4 cm (Table 2). This finding was probably due to more competition for solar radiation. N also had an effect on plant height. *Colocasia* given 40 kg N/ha was 14.9 cm taller than that given no N (65.1 as compared with 80.0 cm). Thus, a symptom of deficiency of N was stunting as was general chlorosis of the leaves. The lower leaves died rather quickly.

Table 3. The effects of nitrogen application on the flowering of 12 plots of *Colocasia*.

Nitrogen (kg/ha)	Plots in which flowering was observed	Plants flowering	Mean (%)
0	6	17	4.3
40	11	47	11.8
80	8	29	7.3

Flowering was observed under field conditions to be more abundant on plots that received N than on plots without N. Spacing did not have any noticeable effect on flowering (Table 3).

As this work is preliminary, more detailed work is necessary on the combined effect of population and fertilizers for the different cocoyams under the Nigerian environment. Further investigation is especially important in the Southeastern zone where annual rainfall is often more than 2000 mm with consequent leaching of both applied and native N. The sandy nature of the soil with low organic matter, total nitrogen, and phosphate suggests that these nutrients among others will continue to be limiting.

The Director, National Root Crops Research Institute, Umudike, granted us permission to present this paper. Thanks are due to Dr Odurukwe for help with statistical analysis and to Mr Arene for helpful suggestions.

ABSTRACTS

The following are abstracts of papers that were presented in summary form during the symposium.

CASSAVA RESEARCH PROGRAM IN LIBERIA

MALLIK A-AS-SAQUI

ROOT AND TUBER IMPROVEMENT PROGRAM, CENTRAL AGRICULTURAL RESEARCH INSTITUTE, SUAKOKO, LIBERIA

Because cassava is second only to rice in importance as a food crop in Liberia, a cassava research program has been initiated at the Central Agricultural Research Institute of the Ministry of Agriculture in collaboration with the International Institute of Tropical Agriculture with aims at improvement in the yields and quality of the crop. Therefore, thousands of cassava genotypes have been introduced for selection and evaluation. Already some disease-free high yielding clones have been identified, and they are under further study in different ecological conditions of the country before their release to the farmers. Present results and performances of most of the introduced clones from IITA show excellent future for a successful cassava program in Liberia.

Le manioc (*Manihot esculenta cranz.*) est après le riz la plus importante culture du Liberia; aussi, l'Institut central de recherche agricole du Ministère de l'agriculture a établi un programme de recherche sur le manioc en participation avec l'Institut international d'agriculture tropicale, en vue d'en améliorer la qualité et les rendements. Des milliers de génotypes de manioc ont été introduits, sélectionnés et évalués. Les clônes sains à rendement élevé déjà sélectionnés sont actuellement à l'étude dans diverses conditions écologiques avant d'être distribués aux cultivateurs. Les résultats actuels et les performances de la plupart des clônes introduits par l'IITA font espérer le succès du programme de recherche sur le manioc au Liberia.

EFFECT OF CASSAVA MOSAIC ON YIELD OF CASSAVA

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Cassava stakes of two cultivars taken from mother plants showing no mosaic, mild, moderate, and severe cassava mosaic symptoms were planted in a split plot design experiment. The plants were sprayed with an insecticide monthly. For two seasons, average yield losses over the control were 7%, 51%, and 66% for the cultivar Gomani; and 23%, 72%, and 82% for cultivar Mbumdumali for the mild, moderate, and severe symptom source stakes, respectively.

Des boutures de deux cultivars de manioc dont les pieds-mères ne présentaient aucun signe léger, modéré ou grave d'attaque de mosaïque ont été plantées dans une parcelle d'essai. Tous les mois, les plants ont été arrosés avec un insecticide. La moyenne des pertes de rendement obtenues au cours des deux saisons d'expérience, par rapport à la culture-témoin, a été de 7%, 51% et 66% pour le cultivar *Gomani*; de 23%, 72% et 82% respectivement chez les cultivars *Mbumdumali* atteints de mosaïque sous forme légère, modérée et grave.

EFFECTS OF GREEN MANURE ON CASSAVA YIELD

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Green manure is a legume or other nutrient-rich crop that is grown for the sole purpose of fertilization and is plowed into the field instead of being harvested. It is used in China as a substitute for the more expensive chemical fertilizers. As part of the Root and Tuber Project in Liberia, I studied the effects of green manure on a local variety of cassava (ME2) grown in rich sandy loam. My aim was to determine the effects on root and shoot yield. The experiment was done on two plots; on one, peanut was planted, and the other — the control — was left fallow. When the peanut was ready for harvest, both plots were plowed and harrowed. Later, cassava stakes were planted on the plots. At 5, 6, and 14 months after the planting date, I weighed shoots and roots from 23 samples. At all sampling times, the root and shoot yields for the manured plot were greater than those for the control.

Les engrais verts sont des légumineuses ou des plantes riches en éléments nutritifs cultivées uniquement dans le but d'amender les terres au moyen d'un labour d'enfouissement. Cette méthode est utilisée en Chine où elle remplace les engrais chimiques plus coûteux. L'incidence des engrais verts sur une variété locale de manioc (ME2) cultivée sur un sol sablo-argileux riche est étudiée dans le cadre du projet sur les tubercules et les racines du Nigeria. L'objet de l'étude est la détermination de l'impact sur les rendements en pousses et en racines. Les études ont été effectuées sur deux parcelles d'essai : la 1ère a été plantée d'arachides et la seconde, parcelle-témoin, a été laissée en jachère. Après la récolte d'arachides, les deux terrains ont été hersés, labourés et plantés de manioc un peu plus tard. Vingt-trois échantillons de pousses et de tubercules ont été recueillis, 5, 6 et 14 mois suivant la plantation. Preuve a été faite à chaque observation, que les rendements étaient plus élevés sur la parcelle amendée que sur la parcelle-témoin.

ALLEVIATING THE LABOUR PROBLEM IN YAM PRODUCTION: CULTIVATION WITHOUT STAKES OR MANUAL WEEDING

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Research over several years at the University of Ife, Nigeria, has led to the evolution of an agronomic package for yam production with minimum labour. The laborious processes of staking and hoe (hand) weeding are completely eliminated. The three essential aspects of the package are controlling weeds by a single application of ametryne and paraquat at 3-6 weeks after planting date; planting the crop at high density (~20 000 stands/ha); and growing the crop without any stakes or supports whatsoever. With 150-g setts of *Dioscorea alata*, the new package has yielded as well as the conventional system where staking and hoe-weeding are practiced. With 300-g setts, the new package yielded lower, but the savings in labour adequately compensate for the yield decline. Further refinements to the new labour-saving package are in progress.

Les années de recherche que l'Université d'Ife, Nigeria a consacrées à la culture de l'igname ont débouché sur la mise au point d'un ensemble économique qui en permet la production avec une économie de travail considérable. Deux opérations laborieuses ont été supprimées, la tuteurisation et le sarclage. Les trois opérations principales de cet ensemble sont le désherbage par une seule application d'amétryne et de Paraquat entre 3 et 6 semaines après la plantation; une forte densité de plantation, soit à peu près 20 000 plants par hectare; la culture sans tuteur d'aucune sorte. L'application de l'ensemble agricole à des semenceaux de *Dioscorea alata* de 150 g a donné une récolte comparable à celle obtenue par les pratiques traditionnelles avec sarclage et tuteurage. Les essais réalisés avec des semenceaux de 300 g ont donné des rendements plus faibles, largement compensés par l'économie de travail. On apporte actuellement les dernières améliorations à ce nouveau procédé.

DISCUSSION SUMMARY

STRATEGIES FOR THE 1980S

Some problems limit improvement of all root crops in Africa, for instance, restrictions on the transfer of germ plasm from researchers in one country to those in another; production costs; and personnel shortages. Because important germ plasms of root crops, including the minor ones, are scattered throughout the continent, there is a need to collect, assemble, evaluate, document, and eventually distribute them to all the countries in Africa. However, as these tasks cannot be accomplished without the cooperation of the quarantine services, the International Society of Tropical Root Crops — Africa Branch in collaboration with the Inter-African Phytosanitary Council must develop safe procedures to facilitate the movement of germ plasm. To realize the full potential of root crop cultivars, researchers need to study the broad effects of the interaction of genotypes and the environment based on agroecological zones. Also, the income elasticity of demand for various root crops must be improved so that it compares favourably with that for other food crops, especially cereals. Therefore, the strategy is to develop technologies for processing, packaging, storing, and marketing of root crops within countries as well as for trade among countries. Finally, more personnel must be encouraged to work on root crops; therefore, existing training programs must be intensified to produce the required capability for research, extension, and production of root crops.

CASSAVA

Considering the importance of cassava as a major food crop in Africa and cognizant of the current work being done on it at various research centres, especially IITA, Ibadan; NRCRI, Umudike; and PRONAM, Zaire; the participants recommended that:

- In studies on pest control, emphasis be placed on breeding cassava for resistance to cassava mealybug and green spider mite, which are currently the major insect pests, and studies on biological, cultural, and chemical control of these pests also be pursued;
- In studies on diseases, researchers use uniform genotypes through cassava tissue cultures now available at IITA and detail information on environment so that their results can be meaningfully compared;
- Yield losses from diseases be calculated on the basis of an interdisciplinary approach to the local ecological systems;
- The nutritional value of leaves and roots of new varieties be thoroughly evaluated with special reference to consumer acceptance, and the value of unexplored but potentially important genotypes, e.g., the yellow-pigmented cassava (*Bankye Borode*), be assessed;
- The agroecological zones worked out by the Food and Agriculture Organi-

zation (FAO) for cassava be studied and utilized for potential expansion of cassava production;
- When intercropping is practiced, weed control, soil conservation, and economics be included in an evaluation of the system; and
- Fertilizer recommendations be based on the nutrient status of the local soil.

YAMS

Several papers and a panel discussion focused on the proposition that yams are threatened with extinction. However, the consensus was that, as long as yam eaters exist, the crop will continue to be in demand, as it forms an integral part of several African cultures. Still, the participants recognized some serious production constraints with regard to cost. They also recognized that the prospects for yam improvement are limited because of the scarcity of basic scientific information and active researchers. The strategies recommended for improvement and increased production of yams were that:

- Efforts be directed at increased government participation and support for yam research;
- That donor agencies be persuaded to contribute significantly toward yam research; and
- Research focus on the search for cultivars with characters that contribute toward alleviating production constraints such as staking and manual harvesting.

COCOYAMS

Despite their importance in the diets of many Africans, cocoyams have received negligible attention and low research priority. The participants recognized the need for efforts toward the improvement of cocoyams, especially with respect to productivity, and recommended that:

- The relevant components of a technological package for increased production be identified;
- Methods for the production of disease-free planting materials be developed; and
- Cultivars with superior postharvest-handling qualities be identified and their use widely encouraged.

SWEET POTATOES

Sweet potato is becoming increasingly important in the cropping systems of the humid tropics. However, some of the peculiar production problems, for example, susceptibility to weevil damage and virus diseases, have yet to be adequately tackled. The tremendous potential for the utilization of the protein content of the leaves has also not been adequately exploited. The participants, therefore, recommended that:

- Appropriate measures to control the weevil and virus disease problems be sought; and
- Selection be aimed toward high-yielding and nutritionally superior varieties in terms of roots and leaves.

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