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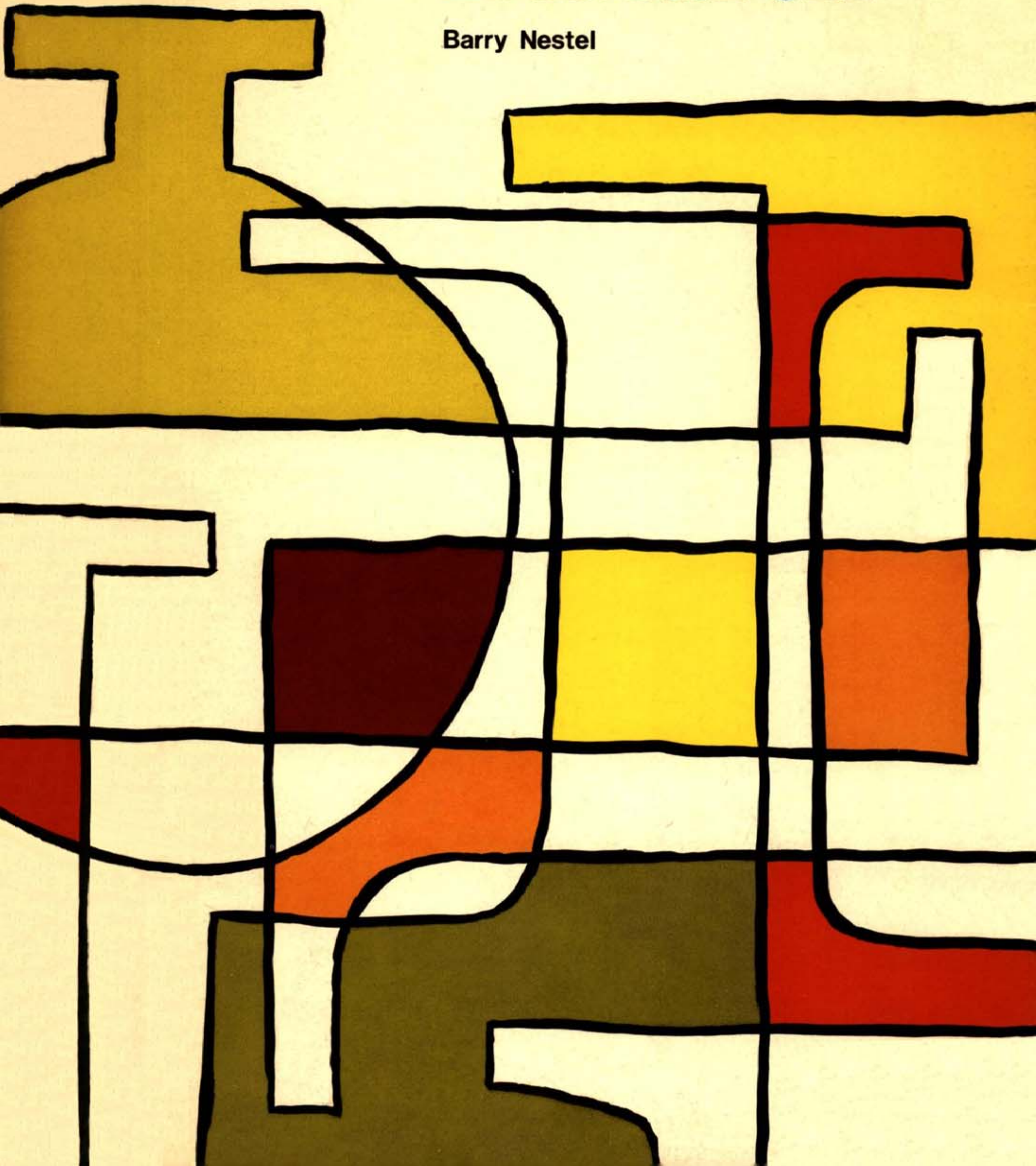
Current Trends in Cassava Research

Barry Nestel



Abstract

Cassava, long a crop neglected by research workers, is now receiving attention at both national and international research centres, with the largest ever research program for this commodity being provided by the International Centre for Tropical Agriculture (CIAT) in Colombia. The significance of the crop in tropical agriculture and its growth potential, especially as an animal feed, have recently been widely recognized. The recent literature, and a substantial volume of unpublished ongoing work, are reviewed under the headings of cassava as human and animal food, enrichment and fortification, toxicity, industrial use, economics of production, genetic improvement, diseases and pests, factors affecting yield, and improved information systems. A multidisciplinary approach to cassava research and a greater research input are recommended.

Résumé

Le manioc, culture longtemps négligée par les chercheurs, fait maintenant l'objet de l'attention des centres de recherches tant nationaux qu'internationaux, le programme de recherches le plus vaste jamais entrepris à ce sujet étant celui du Centre International d'Agriculture Tropicale (CIAT), dont le siège est en Colombie. L'importance de cette plante pour l'agriculture tropicale, ainsi que ses possibilités croissantes d'emploi, notamment pour l'alimentation du bétail, font depuis quelque temps l'objet d'une reconnaissance unanime. L'auteur passe en revue les textes connus récents, aussi bien que de ceux, non publiés, concernant les travaux en cours, sous les titres: le manioc dans l'alimentation humaine et animale, son enrichissement, sa complémentation, sa toxicité, ses utilisations industrielles, son économie de production, son amélioration génétique, ses maladies et ses parasites, les facteurs influant sur son rendement et l'amélioration des systèmes d'information le concernant. L'auteur recommande une formulation multidisciplinaire des recherches sur le manioc et la mise à la disposition de ces dernières de moyens plus importants.

Resumen

La mandioca, un cultivo olvidado durante mucho tiempo por los investigadores, ha despertado ultimamente el interés de los centros de investigación tanto a nivel nacional como internacional; hasta ahora el mayor de los programas de investigación sobre este cultivo se está llevando a cabo en el Centro Internacional de Agricultura Tropical (CIAT) en Colombia. Solo recientemente ha sido reconocido el valor de su cultivo en los trópicos y su capacidad de producción, especialmente como alimento para animales. Un recuento de las publicaciones recientes y de una cantidad apreciable de trabajo actualmente en desarrollo que no ha sido publicado, aparece bajo el título: la mandioca como alimento para humanos y animales, su enriquecimiento y fortalecimiento, toxicidad, utilización en la industria, economia de su producción, mejoramiento genético, enfermedades y pestes, factores que afectan su rendimiento y sistemas mejorados de información. Se recomienda un mayor esfuerzo investigativo y un enfoque multidisciplinario en la investigación sobre mandioca.

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Cassava grows on poor soils throughout large areas of the humid tropics

Preface

This report is a revised and updated version of a paper presented at the Third International Symposium on Tropical Root Crops held at the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, 2–9 December 1973. It attempts to bring together knowledge on the current status of the new and expanding global cassava research network centred at the International Centre for Tropical Agriculture (CIAT) in Colombia.

Since this report represents a status review it refers not only to recent publications but also to a number of papers that will be published in the proceedings of the Ibadan Symposium and to various personal communications regarding ongoing but, as yet, unpublished cassava research with which the author is acquainted.

This is the fifth publication on cassava with which the International Development Research Centre (IDRC) has been associated. Earlier titles are:

(1) report of a CIAT/IDRC-sponsored cassava program review, Cali, January 1972; published by CIAT, Apartado Aéreo 67-13, Cali, Colombia;

(2) report on an IITA/IDRC-sponsored workshop on cassava mosaic, Ibadan, December 1972; published by IITA, Ibadan, Nigeria;

(3) Nestel, B. L., and R. MacIntyre [ed.], 1973, *Chronic cassava toxicity: proceedings of an interdisciplinary workshop, London, 29–30 January 1973;* published by IDRC, Ottawa, Canada;

(4) Phillips, T. P., 1974, *Cassava Utilization and Potential Markets;* published by IDRC, Ottawa, Canada.

For more detailed information on the cassava programs at CIAT and IITA the interested reader is referred to the 1973 annual reports of these two international institutes.

In conjunction with IDRC, CIAT is now providing, for a nominal fee, a set of keyword coded abstracts of the world literature dealing with cassava. About 2000 papers have been processed already and most of the known residual 1500 papers are on order or have been obtained for abstracting. Persons interested in subscribing to this service should contact Dr Fernando Monge, the librarian at CIAT, for further information.

In compiling this report I have received assistance from many of the scientists whose work is quoted. Nevertheless the title is sufficiently ambitious that both errors and omissions are certain to exist and I would be happy to have them brought to my attention.

BARRY L. NESTEL
Bogota, June 1974

Harvested roots are trucked to chipping plants for chipping and sun-drying to produce chips or pellets for use as animal food

Introduction

One of the most thoughtful and perceptive contributions to the Second International Symposium on Tropical Root Crops in Hawaii was presented by Frank Martin (1970) in his paper entitled "Cassava in the World of Tomorrow." Martin postulated that cassava represented an untapped resource in tropical agriculture and indicated what he felt was the type of research program required before the potential of this commodity could be properly assessed and exploited. In some senses Martin's paper turned out to be prophetic in that within a year of its presentation, the international centres for tropical agriculture in Colombia (CIAT) and Nigeria (IITA) both decided to give priority to cassava in their research programs.

Prior to 1971 the global resources available for cassava research were extremely limited and, with the exception of the Central Tuber Crop Research Institute (CTCRI) at Trivandrum in India, the work was being carried out by individual scientists, usually with limited financial support, rather than by multidisciplinary teams. In the last 2 years this picture has changed dramatically. CIAT now has a team of scientists from nine different disciplines, supported by basic research in Canada, dealing with a number of specific problems, with the total annual budget of this joint program exceeding $1 million. The new multimillion dollar research and training centre at CIAT is already receiving scientists for training in cassava research, especially in experimental methodology, not only from Latin America but also from Asia and Africa. Thus, the framework has been established for constructing an international network of cassava researchers somewhat analogous to that which already exists for wheat and rice.

CIAT is fortunate in that Latin America is free from the problem of cassava mosaic disease, which causes serious losses in Africa and India. IITA's cassava program is designed to work specifically on this problem through the disciplines of breeding, entomology, and pathology, with subsidiary support from other scientists and network links into other African countries. Like CIAT, with which it has close links, this institution has excellent research and training facilities and is able to devote more resources to cassava than have hitherto been available throughout Africa.

However, although the resources of international centres can do much in the way of basic and applied research and training, their impact on farm productivity has ultimately to be transmitted via national institutions, which have traditionally paid very little attention to cassava except in the case of India, where for the last decade the Central Tuber Crops Research Institute has operated with a rather tight budget. Fortunately other good new national programs are beginning to emerge. One of the newest and largest is in the new Brazilian national agriculture research institution (EMBRAPA). In addition there is a particularly broad-based and dynamic multidisciplinary team at the University of Bahia (Anon. 1972*a*) funded by the private sector and counselled by E. S. Normanha. Stronger (and in most cases new) national programs are also under discussion in Peru, Malaysia, and Thailand and in some African countries, and the private sector (Brascan Nordeste in Brazil, Uniroyal in Indonesia, and Bookers in Guyana) is also beginning to look at the potential of this crop.

Probably the most important reason for this sudden upsurge of interest in cassava is the development of an export market for chips and pellets that is now worth about US $100 million a year. However, the potential for growth in this market and the likely increase in the use of cassava for food (Phillips 1974), together with the general lack of knowledge about the crop, in spite of its phenomenal energy-producing potential, (Coursey and Haynes 1970) appear to have led to some rethinking regarding the role of cassava as a converter of incident solar energy into energy-rich foods and feeds.

During the last 2 years, I have been associated with the management of research funds specially allocated for cassava and it has been my fortune to travel extensively throughout the tropical world and to visit many of the relatively small groups of researchers interested in this crop. In this paper I will endeavour to present an overall assessment of the current situation with respect to cassava research in the hope that this will provide a discussion on priorities and stimulate the provision of further information on unpublished and current research activities.

I have deliberately biased my presentation towards the utilization side primarily because almost all the papers at the symposium where this report was first presented dealt with cassava *production* rather than *utilization*, and many readers will already be well briefed on the agricultural aspects of the commodity. The second reason for stressing utilization is that I have the distinct impression that the possibility of higher yields will be demonstrated within a relatively short time. However, unless these yields can be produced, stored, dried, marketed, and effectively utilized at competitive prices, we may find ourselves, because of the very perishable nature of cassava, with even greater problems than occurred when the "green revolution" passed its "take-off" stage.

Chipping is usually carried out using small-scale machinery in a labour-intensive system

Cassava as a Human Food

The most important use of cassava is as a human food. Although data on this are notoriously unreliable, their quality is improving. Current FAO estimates indicate that about 55 million tons out of an annual global production of 98 million tons are consumed by humans. Phillips (1974) has projected that by 1980 consumption will rise to about 71 million tons. In parts of West Africa cassava appears to be the most economical subsistence crop and evidence exists to indicate that it is displacing yams and other root crops in some regions.

Table 1 indicates those countries in which human cassava intake appeared to be highest in the mid 1960's. These national data do disguise regional differences within countries. For example, Nicol (1952) found that 25 – 56% of dietary calories in Southern Nigeria came from cassava (as opposed to a national figure of 15% in Table 1). Likewise, as opposed to the Indonesian figure of 15% in Table 1, Bailey's (1961) surveys in Java indicated areas where the calorie intake from cassava exceeded 63%. Normanha (1970) recorded urban intakes of 42 kg/caput and rural ones of 200 kg/caput to give a national average intake of 124 kg in Brazil in the early 1960's.

The form in which cassava is consumed is very varied and traditional processing procedures may be very complex (Coursey 1973). They are also frequently labour-intensive and recently a process has been developed for mechanizing the processing of gari, one of the most popular forms in which fermented cassava is consumed in West Africa (Akinrele et al. 1971). A preliminary report from Ghana (Dovlo 1972) indicates that the mechanized gari has high consumer acceptability. Gari production is, however, an important source of employment and a study is presently underway at the University of Ife to examine the socioeconomic implications of mechanizing this traditional process using both intermediate and modern technology (Kaplinski 1974).

At the Food Research Institute in Ghana an "instant" fufu powder has been developed and is being commercially produced (Dovlo 1972). Miche (1971) has pointed out that the industrial manufacture of traditional African dishes will not only encounter all the classic difficulties met by the development of agro-industry in the tropics but will also have to build on a raw material that has not yet been the subject of extensive research. He suggested that it will be necessary to develop roots of uniform, simple shape with a thin skin, high dry matter content, high degree of consumer acceptability, and good storage potential. A number of these characteristics have been identified in the CIAT cultivar collection (and this issue is also discussed in the paper by Onochie and Makajuola 1973) but a great deal more work is needed before the necessary characteristics can be successfully incorporated into high-yielding ideotypes.

Some promising progress has been made in the storage field in which the literature has recently been reviewed by Ingram and Humphries (1972). They refer to experiences in both India (Singh and Mathur 1953) and Venezuela (Czyhrinciw and Jaffe 1951) using low-temperature storage, and to preservation by waxing, a technique that has received some publicity in Colombia recently (Young et al. 1971) where it is claimed to have considerably extended shelf life.

Table 1. Human intake of cassava in 14 countries 1964–66 (source: FAO Food Balance Sheets 1964–66).

	Human population (*million*)	Cassava as % total caloric intake	Cal/day from cassava	Cassava per year (*kg*)
Congo (Brazzaville)	0.84	54.8	1184	470
Zaire	15.63	58.5	1193	437
Central African Rep.	1.33	48.7	1057	354
Gabon	0.46	47.0	1027	342
Mozambique	6.96	42.6	908	304
Angola	5.15	34.5	659	220
Liberia	1.08	26.2	600	201
Togo	1.64	26.5	590	197
Dahomey	2.36	20.1	438	148
Paraguay	2.03	19.7	540	181
Ghana	8.14	18.2	380	130
Brazil	80.77	10.8	274	107
Nigeria	58.48	14.1	306	103
Indonesia	105.74	15.3	269	92
Total	304.15	–	–	–
Weighted average (14 countries)	–	19.4	374	124

More recently Booth (1973*a*) has reported on a technique that extends both post-harvest on-farm storage and shelf life. In another paper, Booth (1973*b*) has stressed the importance of mechanical damage in post-harvest losses, and confirms the observation of Averre (1967) that vascular streaking of cassava roots commences at cut surfaces. Averre's (1967, 1970) claims that vascular streaking is enzymatic in nature received some support from the identification by Czyhrinciw (1969) of peroxidase and catalase in fresh cassava. However, Montaldo (1973) suggested that factors other than enzymes might be associated with vascular streaking and noted some varietal resistance to this condition. Further work to understand the principles of post-harvest losses appears to be warranted.

Enriched and Fortified Cassava

Because of its low protein content the nutritional enrichment of cassava has received a great deal of attention. Some work has been carried out with enriching traditional products such as gari (Akinrele 1967) and cassava soups and porridges (Mosha 1972), but major attention has been given to fortification of cassava flour with soy protein isolate or soya grits. This has been extensively studied in Brazil (Anon. 1972*b*) where cassava flour is widely used in the production of composite flours as substitutes for wheat flours. USAID is also supporting studies on fortified cassava in Nigeria and Zaire. At present the problem of using fortified cassava flour appears to be more one of economics than of technology, in that the protein-deficient sector of the population seldom has the cash to purchase any type of processed flour.

The subject of composite flours has received attention from the Institute for Cereals, Flour and Bread (TNO) at Wageningen in Holland, the Central Food Technological Research Institute at Mysore in India, the Instituto de Tecnología Agrícola e Alimentar in Rio de Janeiro, and the Instituto de Investigaciones Tecnológicas in Bogota. It was exhaustively reviewed at a meeting sponsored by the Study Group on Composite Flours of the International Association for Cereal Chemistry in Bogota in October 1972. During the last decade remarkable progress appears to have been made in the use of non-wheat flours and starches (particularly cassava) as total or partial substitutes for wheat flour in bread making (Kim and Ruiter 1968; Pringle et al. 1969; Perten 1970; Dendy et al. 1970) and a bibliography on this subject appeared recently (Dendy et al. 1972).

Composite flours not only dilute the wheat gluten but also change the concentration and characteristics of other components that affect bread-making properties. The role of non-wheat starches and their effect on dough quality has been reported on by Hoseney et al. (1971) and the role of gluten substitutes examined by Lagendijk and Pennings (1970) and Rasper et al. (1972), who have studied the structural development of dough and its visco-elastic properties in cassava-fortified mixes. Research under way by Bushuk (1973) in Manitoba is showing promising progress toward the development of a simple process of mechanical mixing that improves the quality of bread made from flour containing cassava. Technical and economic issues still remain to be resolved in the composite flour field, but present and projected demands and the relative prices for wheat and cassava do seem to indicate that cassava-fortified flours could play an increasingly significant role in the future.

The potential for using cassava as a substrate for the production of fungal protein was reported on by Gray and Abou-El-Seoud (1966) and later expanded upon by Stanton and Wallbridge (1969). More recently Strassner et al. (1970) described a pilot plant process for which they prepared preliminary cost estimates for a 10-ton/day plant. In 1973 Gregory and Reade developed a process using an *Aspergillus* sp., which grows on a liquid cassava substrate at 50°C (pH 3.5). This process appears to have a potential for producing animal feed of 15% protein content from cassava at a relatively low cost under conditions that may be practical at a field scale in cassava-producing areas. It is expected to undergo testing on a pilot plant scale at CIAT in late 1974. Related work is also under way by Hutagalung and Stanton in Malaysia using a solid cassava substrate and *Rhizobus* sp.

Cassava as an Animal Feed

Although the early work on fungal enrichment of cassava was related to the need to improve human protein intakes, current activities in this field tend to be more livestock-oriented. The work of Gregory and Reade is particularly related to the use of residues from cassava (tapioca) starch factories. These residues are already used extensively as pig feed. The magnitude of this practice is difficult to estimate in the absence of data on cassava starch production, although Mahendranathan (1971) calculated that the production of starch factory residues in Malaysia alone totalled about 300,000 tons per annum; obviously a means of raising the protein level of this from 2 to 15% could have important implications for the pig industry.

The main thrust of work on livestock feeding with cassava is, however, based on the use of raw or dried roots. Preliminary work on this was carried out in the 1930's in Malaya, although the modern literature appears to originate from the paper by Oyenuga and Opeke in 1957. More recently the work has been spearheaded by Maner and his associates at CIAT, by a group of workers at the University of Malaysia, and by Müller in Singapore.

Much of this research is being done in countries that are not major cassava producers in world terms and the major current users of cassava in animal feed are feed compounders in the European Economic Community (EEC) who import much of their cassava from Thailand where it is seldom fed to either man or livestock. European use of cassava in animal feed has resulted from its favourable price compared to feed grains in countries deficient in feed energy. At present, cassava seldom comprises more than 10% of compound feeds, although on occasion it has been used at levels as high as 40% and in some of the tropical trials its level has reached 60%. The real potential for using cassava for animal feed appears to lie in cassava-producing countries, especially those in which the pressure of demand is leading to increasing prices for animal products and where a market for quality meat is developing.

Müller et al. (1971) found that cassava meal substituted for corn up to levels of 60% in broiler rations providing that the diet was balanced and that at higher levels of substitution the cassava was pelletized. Nutritional problems arose when the fibre content of the cassava meal exceeded 3.5%, and economic difficulties when the cassava meal price exceeded 67% of the price of corn. Somewhat similar findings were reported in Mexico by Tejada de Hernandez and Brambila (1969) who were able to use up to 50% cassava meal in rations for young chicks that had a similar growth rate but lower feed efficiency than chicks on corn starch. The authors commented on the wide range of hydrocyanic acid (HCN) levels presented in their rations and the uncertainty regarding its nutritional significance. A similar finding was reported on by Jalaludin and Oh (1972) who fed very high levels of HCN to laying hens without producing toxic effects.

Hamid and Jalaludin (1972) used cassava successfully to replace corn at levels of up to 60% in layers. At higher levels they had difficulty in maintaining the protein content of the ration. Yolk colour became progressively whiter as cassava levels increased, so that a rich source of carotene needed to be added to the ration. There was also some evidence that methionine was a limiting factor on high cassava rations. The carotene level might, however, be of less significance in areas where yellow cassava is produced (Guimaraes and Cresta de Barros 1972).

The use of cassava root meal in both grower and layer diets has been reported from Hawaii (Enriquez and Ross 1972) where egg production, feed conversion, egg weight, and shell thickness have been related to levels of cassava intake.

In swine the most comprehensive work has been carried out at CIAT (Maner 1972, 1973) where up to 60% cassava has been used in the ration. However, at this level, gain and efficiency declined, although these could both be improved by methionine supplementation, which compensated for the low methionine level of the cassava and also provided a sulphur donor for the detoxification of HCN. Hew and Hutagalung (1972) found that feed intake in swine decreased as the cassava level of the ration was increased. Performance improved significantly following the addition of 0.2% methionine to a 50% cassava diet but did not improve with higher methionine levels. The further addition of palm oil (which also enabled the pigs to better utilize higher methionine levels) and glucose (which may have reduced HCN levels by forming glyconohydrin and improving palatability) improved both daily gain and food conversion. From the economic standpoint the fully supplemented 50% cassava ration gave lower (10%) daily gains at a cost per kilogram of gain that was less (3%) than a corn-based ration.

Müller et al. (1972) recommended the use of cassava meal in pig rations when the price of an 85% cassava meal/15% soya meal was significantly cheaper than that of corn. They stressed the importance of pelleting the cassava to avoid bulk and dust problems and the need to balance fibre, mineral, vitamin B, and amino-acid levels. Suggested maximum levels of cassava meal for starter, grower, and finisher rations of different ash and fibre contents were tabulated. These ranged from 0% in starter rations with 5% fibre, to 75% in finisher rations of 2.8% fibre, and contained only cassava, soybean meal, and minerals.

Further recent reports using cassava for swine feeding originate from Fiji (Teleni 1972) and Venezuela (Chicco et al. 1972). A 40% cassava, 29% rice bran ration was shown to require the addition of zinc before it would give gains equivalent to a ration in which corn was the primary energy source, although evidence was not provided to indicate whether the cassava or the rice bran was the source of the reduced availability of zinc (Maust et al. 1972).

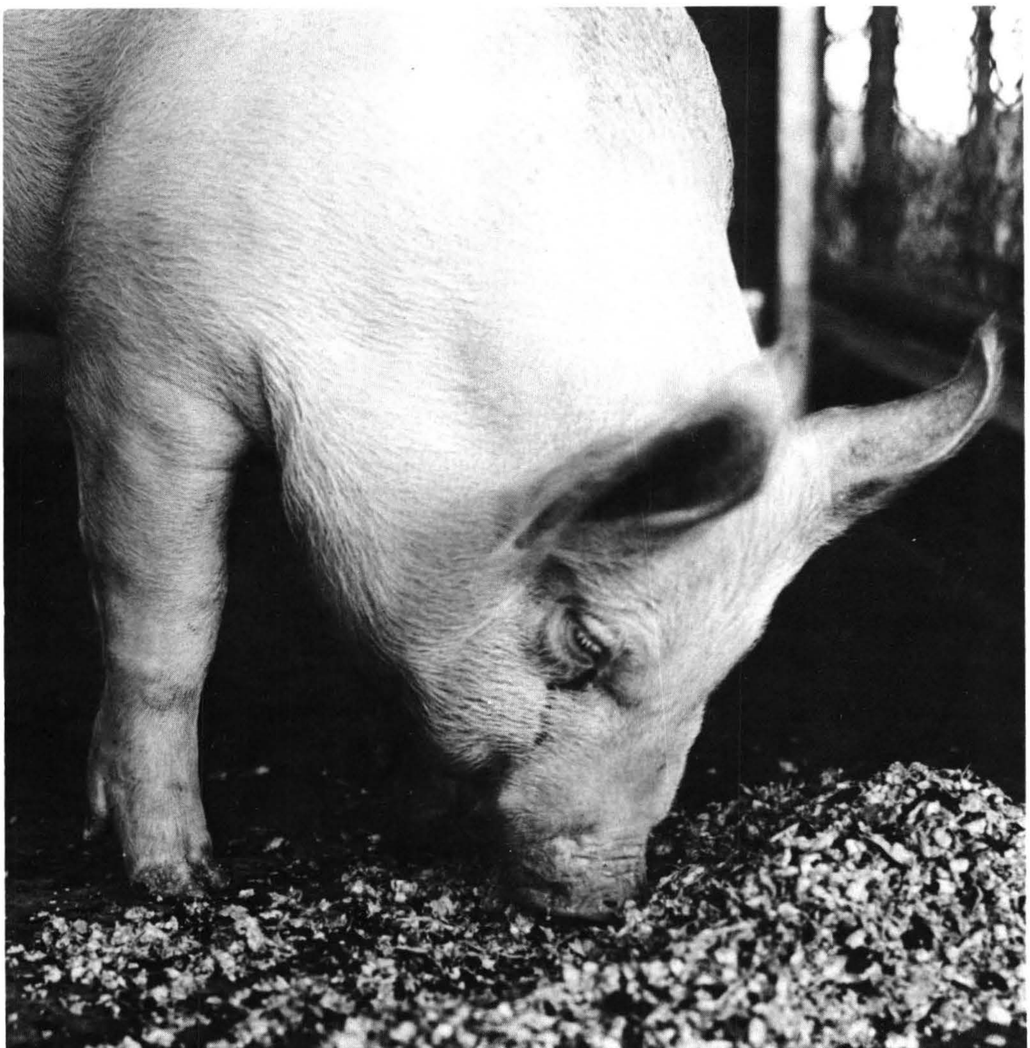
The literature regarding cassava as a ruminant feed appears to be very sparse although Chicco et al. (1971) and Schultz et al. (1970*a*, *b*, 1972) have carried out extensive studies on the use of cassava in conjunction with urea in both bovines and sheep. Chou et al. (1974) have successfully and economically fattened steers in Singapore on a ration composed principally of 60% cassava meal and poultry litter.

In Malagasy, Serres (1969) has reported on the use of cassava roots and leaves as a component of rations for intensive finishing of cattle. Serres and Tillon (1972) have also reported on the production of cassava root silage for pigs (fed 3 kg/day) and cattle (fed 5 kg/day). Extensive trials on the use of cassava root silage as a component of swine rations have also been conducted by Maner. Low protein levels presented a problem and attempts to raise this by microbial action have not been successful (Gregory and Reade 1973).

Serre's work on using cassava leaves for cattle was pre-dated in 1952 by Echandi who was looking for a substitute for alfalfa meal. This work has been followed up in chicken and quail by Ross and Enriquez (1969) and in pigs by Lee (1972) and Lee and Hutagalung (1972). It appears that in both pigs and poultry 20% cassava leaf depresses both liveweight gain and feed conversion but the addition of sodium thiosulphate, methionine, and molasses and/or vegetable oil partially corrects these depressions. Further studies on the cyanide content (Chew 1972) and water soluble protein (Foo and Chew 1972) of cassava leaf have been carried out to help clarify its nutritional value.

Additional work on this subject seems to be necessary since Juarez (1955) reported an annual leaf yield of up to 27 tons/ha from two leaf pickings in Peru, and preliminary data from more frequent picking in Brazil (Bahia) and Colombia (CIAT) seem to suggest that with appropriate management even higher leaf yields may be feasible. Since leaf protein values are between 20 and 30% on a dry matter basis (Rogers 1959), the possible role of cassava leaves as food or feed may need reexamining. Eggum (1970) has already shown that the digestibility of cassava leaf protein in rats was 70–80% although the biological value of the protein was only 44–57%. However, the addition of methionine to the diet raised the biological value of the cassava leaf protein to 80%. A similar result was obtained by Adrian and Peyrot (1971) when adding cassava leaf protein to cereal diets.

Fresh or dried cassava can be used as a carbohydrate source in animal diets.



Cassava Toxicity

In discussing the use of cassava in animal feeding, frequent reference has been made to the subject of toxicity. The cyanogenic glucosides of cassava have been known to be responsible for both acute and chronic toxicity in humans for some time, although the importance of chronic toxicity has been studied extensively only in the last decade. Recent work has indicated not only that high cassava intakes are associated with the incidence of tropical ataxic neuropathy in Africa (Osuntokun 1973), but that in the presence of marginal iodine and low protein intakes, high cassava diets may be a permissive factor in the development of goitre and cretinism (Ekpechi 1973; Ermans et al. 1973). Domestic livestock are seldom fed high levels of cassava for prolonged periods but nevertheless there is evidence to indicate that impaired growth occurs in pigs and poultry on high cassava diets unless these are supplemented with methionine (Maner and Gomez 1973).

A recent workshop reviewed in depth the subject of chronic cassava toxicity, relating the biosynthesis of cyanogenic glucosides (Butler et al. 1973; Conn 1973; Nartey 1973), the agronomic and physiological aspects of cassava toxicity (De Bruijn 1973*a*), and detoxification mechanisms (Coursey 1973; Oke 1973) to the theme of human toxicity. Subsequent to this meeting, Farnden et al. (1973) reported further on the role of aldoximes and nitriles as intermediates in the biosynthesis of cyanogenic glucosides.

Chronic cassava toxicity: proceedings of an interdisciplinary workshop, London, England (Nestel and MacIntyre 1973) contains 18 papers and a number of recommendations for future lines of research. Amongst these was the need to ensure that breeding for low cyanide varieties would not increase the susceptibility to pathogens and pests. The techniques and problems of adequate assay were also subjects that received considerable attention since the cyanide in cassava results from the breakdown of relatively stable linamarin and lotaustralin whose own toxicity is unknown. There have been several recent papers (Esquivel and Marvalhas 1973; Sadik 1973; Zitnak 1973) dealing with cyanogen assay in cassava roots and leaves, but the relevance of rapid assay techniques to the problem of toxicity appears to require further clarification, especially since both CIAT and IITA are selecting for low cyanogen levels.

Cassava has also been incriminated in problems of aflatoxicity since it appears to be an excellent growth medium for *Aspergillus flavus*. Samples of cassava flour from Brazil have relatively high levels of aflatoxins and at one time it was thought that this might be associated with the high incidence of black fever in children on the upper Amazon (Boshell 1968).

More extensive studies with cassava starch in Thailand and in Hong Kong (Shank et al. 1972) and in fermented cassava from Dahomey (Toury and Giorgi 1966) have also shown the presence of aflatoxins, and an aflatoxin-like factor has been recorded in India (Nagarajan et al. 1973). In a field study in Uganda (Serck-Hanssen 1970) there was circumstantial evidence that a highly contaminated cassava sample may have been involved in a documented poisoning episode. However, by and large, particularly in view of the varied ways in which cassava is handled after harvest, there appears to be little evidence that aflatoxins present a significant problem.

Industrial Use of Cassava

Apart from its use as direct food and feed, cassava is used in the food industry, principally in the form of starch. The low-amylose high-amylopectin content of cassava starch give it unusual viscosity characteristics and great dimensional strength, and these find a number of specialized uses (Ayres 1972). The characteristics and behaviour of this starch have been studied in great detail by Rasper (1969*a*, *b*, 1971), Banks et al. (1972), Srivasta and Patel (1973), Valikaya and Nguen (1971), and by several Brazilian workers (Rosenthal et al. 1972; Mors 1972).

Cassava can be hydrolyzed to produce glucose (Park and Lima 1973). A feasibility study for a cassava-based glucose industry has been carried out in Nigeria (Dina and Akinrele 1970) and the process is used commercially in Colombia, India, and Singapore. It can also be converted to alcohol (Teixeira 1970). However, this process does not yet appear to be used industrially although the current fuel-oil price situation appears to have led to a recent reassessment of the potential of this process in India.

Dextrins made from cassava flour can be used to make adhesives that are superior to starch-based adhesives in a number of characteristics (Evans and Wurzburg 1967). Cassava stalks have also been used to make particle board (Flaws and Palmer 1968) on an experimental scale.

The technology for processing cassava has been described in some detail by Grace (1971) and the commercially available machinery listed by Ingram (1972). The processing procedures used are very traditional although some modernization of the cassava starch industry has taken place recently. The last 2 years have also seen an interest in improving the drying of cassava chips. A simple solar heat drier suitable for cassava was described by Williams et al. (1969) and a pilot solar drier of another type is currently undergoing tests in Trinidad (Springer 1972). The drying characteristics of cassava are also being studied by Roa (1973) who has developed machinery for producing cassava bars ($1 \times 1 \times 0.5$ cm) directly from roots. However, none of these new techniques appear to have been evaluated economically in terms of current drying practices, for which concrete yards are normally used. A variety of chip sizes and shapes are produced and there appears to be an urgent need for further research on the optimum size and shape of chips and, perhaps, on a simple technology to reduce radiation losses in drying yards.

This need for improvement in current drying and pressing techniques was stressed in a study by Mathot (1972), which pointed out that these procedures could lead to substantial improvements in both quality and prices for cassava pellets exported from Thailand (which supplies the bulk of world trade in this item).

Economics of Cassava Production

In order to exploit the markets for cassava, it has to be sold at a price that is competitive. To some degree this depends on the use to which the crop is put. Thus the Thai farmer who grows most of the cassava that reaches the world market obtains US $11–12 for the farm-dried chips from a ton of fresh cassava whereas for fresh cassava for human use, the Jamaican farmer obtains 2–4 times this price (Rankine and Houng 1971), and, at certain times of the year, the Colombian farmer may obtain 6–10 times the price obtained by his Thai counterpart. However, generally speaking, the farm price for fresh roots seems to lie in the range of US $10–15 per ton. The current high-price situation for cereals has altered this picture somewhat since this paper was first written. Thus farm gate prices have risen from US $20 to nearly US $40 per ton in India between March 1973 and March 1974 and cost, insurance, and freight prices at European ports have jumped from around $75 per ton to $110 in some cases.

It is difficult to cost cassava production since the main inputs are family labour and land, and in subsistence-farming areas, the land may be communally owned. Brannen (1972) reviewed some of the literature on production costs and found that the usual cost of producing cassava was about US $6 per ton. The major production cost was labour. For a variety of reasons, it is difficult to compare the various labour costings available, but in various surveys the man-hours used to produce a ton of cassava appeared to range from 50 to 150 and to average about 100 (Andersen and Diaz 1973; Brannen 1972; Rankine and Houng 1971; Raeburn et al. 1950). Obviously the return to labour from cassava production is very low, notwithstanding the fact that Raeburn et al. found the yield per man-day from cassava production exceeded that of other tropical staples. Clarke and Haswell (1964) reported a similar finding when comparing both the output value and the labour productivity of various tropical crops in terms of FOA standard wheat equivalents.

The low return to labour relates to the fact that the opportunity costs of labour in many subsistence farming areas is often regarded as being close to zero, otherwise a production cost per ton of US $6 would not be possible. However, we may anticipate that some form of mechanization may be necessary in the future since, as economies develop, labour generally tends to demand a higher return, especially for an unpleasant job such as harvesting cassava (which commonly accounts for 25–30% of the total labour costs). For this reason production costs may be expected to rise in the future. Against this, account must be taken that current cassava yields on small farms are often no more than 10–20% of the production potential of the crop, so that a great deal of scope exists for reducing the costs of production by raising yields. This is especially true if high-yielding varieties can be developed that are not only easily harvested but also retain adequate drought and disease tolerance.

In view of the limited past resources devoted to both the breeding and the mechanization of cassava, compared with those now available, it is difficult to make any forecasts as to the likely future pattern of production costs. What does appear probable is that these costs will be strongly influenced by the results of plant-breeding work in terms of the achievements that are made with respect to yield and morphology.

Andersen and Díaz have examined this situation from the standpoint of public policy and have drawn particular attention to a possible conflict arising between the social objective of employment creation and the profit-maximizing objective of introducing new technology. They point out the labour-intensive nature of cassava production and the adverse effects on employment that could arise from both extensive mechanization of land preparation and the widespread use of chemical herbicides. The impact of mechanization on the labour requirements for planting and harvesting has also been examined by Krochmal (1973) and the economics of mechanization by Dulong (1971) who claimed that very high yield levels would be required for mechanization to be economic in the Malagasy Republic.

However, most efforts at mechanization have disregarded the prospects for developing simple intermediate technologies. The increasing extent to which cassava is displacing yams and other root and tuber crops (especially in West Africa) suggests that it is the most economical subsistence crop in many areas of the tropics. Since mechanization using modern machinery often gives marginal economic benefits, and as energy from fossilized fuels is now very expensive in many cassava-producing countries, greater effort is needed to improve the efficiency of use of both hand and animal labour through development of simple mechanization procedures.

Andersen and Díaz's paper highlights the need for more information on the total economic structure of the cassava industry. The global market for animal feed has been looked at by the International Trade Centre (1968), Phillips (1974), the processing sector in general by Grace (1971), the West Malaysia market by Wahby and Eriksen (1969), and the Malaysian State market of Perak by Chye and Loh (1971). However, integrated studies dealing with production, processing, and marketing are harder to come by. The Ministry of Agriculture in Thailand (Anon. 1973) completed such a study and a similar activity is being pursued in Brazil by the Comissao Nacional de Mandioca and by Dantas (1973) in the Brazilian State of Bahia. Probably the most complete study of the cassava industry at the national level is a recent thesis by Tan (1973) in Malaysia.

At the farm level, a preliminary report (Díaz 1973) was published on a 300-farm survey in five zones of Colombia. This survey attempts to provide detailed information on production practices and to relate these to the CIAT research program. Some farm costing studies involving cassava are also being carried out at IITA and by the team at the University of Bahia in Brazil. However, the absence of adequate economic data would appear to be a constraint from the standpoint of both identifying growth opportunities and attracting new investments. In this context it is of paricular relevance to note that cassava does appear to offer opportunities for labour-intensive production on small farms. Since small farms and rural employment are important issues in many tropical countries, the need for more research on the structure of production and the relationship of this to public policy cannot be overstressed.

Genetic Improvement of Cassava

Even in the absence of detailed agro-economic studies the cassava breeder does have some guidelines to work on. Perhaps foremost amongst these is the need to evaluate the wide range of currently available genetic material. To date very limited attention has been paid to the study of fundamental aspects of the genetics, cytology, and breeding of the crop. Recently, little has been added to the literature in these fields. The current state of knowledge has been covered in a review by Dempsey (1971) and in the reports to the previous and current Tropical Root Crops Symposia by Magoon (1967, 1970) and Magoon and Krishnan (1973). A comprehensive taxonomic classification of *Manihot esculenta* has been prepared by Rogers and Fleming (1973) but this is based entirely on botanic rather than agronomic or economic characteristics.

The main efforts in the plant-breeding field are devoted to increasing yield, although CIAT, CTCRI, and IITA are all screening for cyanogen level and for disease and insect resistance. Plant breeders working with cassava are known to operate in Brazil, Colombia, Costa Rica, India, the Malagasy Republic, and Nigeria, although the number of trained geneticists involved with the crop is still very small. The use of radiation or mutagenic agents has been practiced in Turrialba (Costa Rica), the Malagasy Republic (Dulong 1971), and especially India, where it has been associated with efforts to enhance the protein level of the crop through the production of induced tetraploids (Hrishi and Jos 1973). Colchicine has also been used to induce polyploidy by Magoon et al. (1969) and later by Imam (1972), but significant yield responses do not appear to have followed this treatment.

The recent publication by Rogers and Appan (1973) on the genus *Manihot* represents a useful tool for agronomists and plant breeders interested in cassava improvement. The biosystematic work of these authors has identified some particularly interesting opportunities for further research in interspecific hybridization, which has already been used successfully to produce disease resistance in cassava. In Java, grafts of *M. glaziovii* on *M. esculenta* stock led to the production of enormous roots (up to 100 kg in 24 months) on individual plants, but whether or not this technique has a potential beyond "back yard" production remains to be determined (de Bruijn 1973*b*). Similar but less spectacular increases in yield have been reported from grafting *M. flabellifolia* onto *M. esculenta* (Mogilner et al. 1967) although Rogers and Appan (1973) state that *M. flabellifolia* is the same species as *M. esculenta*.

A recent upsurge of interest in the ethnobotany of cassava may also be of interest to the plant breeder. The role of cassava in the development of civilization in lowland South America was discussed at a Symposium of the American Anthropological Society in November 1971 at which it was postulated that manioc (cassava) use may have predated that of corn. In the same field the evidence regarding the area of origin of *M. esculenta* as a crop plant has recently been reviewed by Lathrap (1973) and by Renvoize (1972).

One major problem associated with efforts to select and improve cassava is the difficulty of moving material around the world because of disease problems. The normal method of propagation by vegetative means accentuates this problem as does the protogynous nature of the plant and the frequency with which pollen sterility occurs. Efforts to overcome this situation are being made by propagation studies (Krochmal 1973; Wholey and Cock 1973).

Wholey and Cock have developed a simple multiplication technique that enables them to produce 18,000 stem cuttings from one plant in 1 year under field conditions. Another possible approach to rapid propagation is through tissue or cell culture. This is being developed primarily to produce mosaic-free plants (Berbee et al. 1973; Kartha et al. 1974) but may also offer possibilities for rapid propagation (and perhaps for the production and dissemination of mosaic-free material), provided that the genetic stability of culture material can be assured.

Great genetic variability exists among cassava cultivars. In excess of 2000 cultivars are being evaluated at CIAT.

Diseases and Pests of Cassava

Mosaic disease in cassava has been the subject of a number of recent studies and the state of current knowledge was reviewed at a workshop held at IITA in December 1972 (IITA 1972). This meeting categorized cassava "mosaics" into:

- *(a)* a mechanically transmitted disease found in Brazil whose causal agent is a virus of the potato virus X group;
- *(b)* a whitefly-transmitted disease found in Africa and India whose causal agent is unknown;
- *(c)* a mycoplasma-induced disease of which at least three occur in Brazil and one in the Ivory Coast.

The meeting was not attended by anyone familiar with mosaic disease in India and the relationship of this to the African and Brazilian mosaics does not appear to have been studied, although in Canada Peterson (1973) has recently established a program that will enable him to look at cassava mosaic from all three geographic sources, and Kitajima and Costa (1973) have recently reported on their EM studies with cassava virus and mycoplasma in Brazil.

The IITA meeting report contains a review of most of the African literature but excludes reference to a paper by Golato (1971) in Ghana and to the most recent contribution by Chant et al. (1971). It also excludes mention of a paper by Ganguly et al. (1970) describing a serodiagnostic method for detecting mosaic-infected plants in the field. This is a subject that may justify further study in view of the magnitude of the losses that cassava mosaic can produce (Narasimhan and Arjunan 1973).

In the last few months IITA (1974) have reported their recent progress in crossbreeding with a cassava line that exhibits a very high degree of resistance to African cassava mosaic although the root yield of this cultivar is poor. It appears that the resistance shown by this cultivar is transmitted fairly readily and a very extensive crossing program is currently under way at IITA. Cultivars that exhibit a good degree of mosaic tolerance in India do not appear to have this characteristic in Nigeria where the prevailing type of mosaic appears to be more pathogenic.

No work on the "brown streak" virus disease of East Africa appears to have been published recently. However, the literature relating to the major bacterial, viral, and fungal diseases of cassava has recently been reviewed in some depth by Lozano and Booth (1974). Their review covers most of the published work in this field in addition to many observations from recent research at CIAT. They draw attention to the large number of diseases, many of them poorly understood, that can attack cassava both before and after harvesting the roots. Little information is available on control measures, except in the case of bacterial blight, which appears to be only recently recognized as a major disease problem in Latin America and Africa.

The presence of cultivars resistant to some disease conditions is noted, as is the need for more information on host–parasite relationships, in order to better understand the nature of this resistance. A similar plea is put forward by Rosseto et al. (1973) and it also appears to be relevant to resistance to insects since van Schoonhoven (1973) has noted varietal differences in tolerance to attack by thrips and spider mites. Both of these pests can be controlled chemically but it appears more economic to select for genetic resistance. The possibility of relating disease and pest resistance to a chemotaxonomic classification of the CIAT and other cultivar collections is being examined by Grant (1973).

The literature on parasitic nematodes associated with cassava appears rather sparse; in his bibliography Montaldo (1967) lists only two species recorded in cassava. There is, however, a recent reference on this subject from Trinidad (Brathwaite 1972). An up-to-date review of insect and acarid pests of cassava also appears to be lacking, although Montaldo lists about 90 species of insect pests as having been found on cassava. Currently detailed work on thrips and spider mites is under way at CIAT. In Uganda the accidental introduction of a neotropical mite, *Mononychellus tanajoa* (Bondar), is causing considerable devastation (Bennett 1973). The mite is being studied by Nyiira (1973).

Research on weed control in cassava also appears to be relatively new. Doll and Piedrahita (1973) at CIAT have a fairly comprehensive program that is of particular interest from the standpoint of the relationships between morphology, yield, and weed control, especially with respect to the cost studies of Andersen and Díaz referred to previously. Doll's work highlights the need for a multidisciplinary approach to cassava research, in which the definition of the ideotype that the plant breeder must seek may be dependent not only on yield but on factors such as disease and insect resistance, weeding costs, ease of harvesting, drought tolerance, fertilizer response, cyanide level, starch composition, etc. The complexities of these interrelationships may imply the necessity for some model-building inputs, once more information is available on the basic production parameters.

Cassava bacterial blight is one of the most widespread and devastating diseases of cassava. Resistance to this disease has been found in about 1% of the CIAT germ plasm collection.

Factors Affecting Yield

It is in these production parameters, particularly "yield," where the major research thrust is taking place at present. This is hardly surprising since yields under farm conditions are frequently reported as averaging only 5–15 tons/ha whereas experimentally it has been claimed that this range can be far surpassed. Dulong (1971) reports 70 tons/ha in the Malagasy Republic, Cock (1973*b*) 47 tons in Colombia, and Schmidt and Pereira (1968) 34 tons in Brazil. These yields are well in excess of those encountered under commercial conditions, although on a recent visit to Malaysia I witnessed the harvesting of a crop on virgin land that was estimated as yielding over 50 tons/ha and I understand from Chan that this is not unusual. At this meeting we have reports on yield responses from Sierra Leone (Godfrey-Sam. Aggrey 1973); Kenya (Gurnah 1973), Peru (Hoffman 1973), Nigeria (Okigbo 1973; Obigbesan and Agboola 1973), and Colombia (Wholey and Cock 1973), and recent papers on this theme also originate from the Seychelles (Smith 1970), Mozambique (Mota 1970), and Malaysia (Chan 1969).

Amongst the factors influencing yield, one that has been relatively neglected in past research efforts is that of the onset and rate of root bulking. Wholey and Cock found that differences in yield after 7 months were caused by variations in the rate rather than in the time of onset of root bulking. However, 7 months may be too early to make decisions on yield maximization. Chan found that a number of his varieties yielded significantly higher at 12 months (but not at 14) than they did at 8 months. His current studies involve harvesting at intervals up to 21 months. There appear to be very great differences in local practices in relation to harvesting age. This factor must obviously be an important component of any systematic study on yield.

Chan and Okigbo have both studied the effects of stake orientation, length, and polarity at planting time on subsequent yield and performance. This is a subject on which the early cassava literature is very rich. There seems to be little consensus on the issue of orientation, although most authors seem to get better growth from longer (20–30 cm) cuttings and to have a fairly high mortality in cuttings planted upside down. Enyi (1970) has also shown that there was a positive linear relationship between root yield and age of planted cutting (this is a subject that may justify reexamination within the context of the rapid propagation technique of Wholey and Cock).

Enyi (1972*a*, *b*, *c*) has also examined the effects of spacing on growth, development, and yield of single and multiple shoot plants. He found that bulking rate was positively related to net assimilation rate and that both net assimilation and tuber yield were higher in single shoot plants. Maximum yields were obtained from a planting density of 12,600 plants/ha. (A further report on this is contained in a more recent paper (Enyi 1973*a*), which has not yet come to hand.)

The relationship between spacing, yield, assimilation, and dry matter distribution has also been examined by Sinha and Nair (1971), Williams and Ghazali (1969), and Williams (1971, 1972), and more recently by Cock (1973*a*), Cuervo (1973), Natarajan and Rengasamy (1973), and Natarajan and Vijayakumar (1973). It appears that leaf area index is suboptimal after 6 months due to leaf fall, although in one variety Cock found that he could compensate for this by raising the plant population as high as 20,000/ha with an associated increase in yield. However, the application of modern techniques and ideas in plant physiology to cassava research is a very new concept and there is obviously scope for more research on factors affecting dry matter production especially leaf area index, leaf inclination, and photosynthesis.

Research on the responses of cassava to fertilizer has given conflicting and generally unsatisfactory results. It has been suggested that high levels of nitrogen may increase leaf production at the expense of roots (Krochmal and Samuels 1970) and in one experiment (da Silva and Freire 1968*a*) phosphorus and potassium applied before planting depressed survival. On the other hand various authors (Chan 1969; Chew 1970; Cock 1973*a*; da Silva and Freire 1968*b*; Vijaya and Aiyer 1969; Yong 1970; Anon. 1971) suggest a positive response to fertilizer, especially nitrogen, although this response is not always significant. Research on fertilizer use is currently underway in a number of stations and is also reported on by Godfrey-Sam. Aggrey and Gurnah.

More basic studies on the mineral nutrition of cassava have been carried out by Forno et al. (1973) in Queensland and by Bates (1973) in Canada, who is preparing a series of colour slides on different levels of element deficiency and toxicity symptoms. This work is being carried out at the University of Guelph, on behalf of CIAT. A related program (Hunt 1973) in the growth rooms at Guelph is examining: *(a)* photosynthesis and (*b*) growth and tuberization in *M. esculenta* and some other *Manihot* species. Growth and tuberization are also being studied in the field in Colombia (Cock 1973*a*), India (Indira and Sinha 1970; Indira and Kurian 1973), New Guinea (Enyi 1973*b*), and Trinidad (Ferguson 1973). Ketiku and Oyenuga (1972) have traced the changes in the carbohydrate constituents of cassava roots during growth. The starch level peaked (81% of the carbohydrates) at 8 months and sugars reached their peak concentration of 5.7% (of which 69% was sucrose) 9 months after planting.

The water requirements of cassava have received little study although it is known to be very drought tolerant. The only paper that I am aware of on this subject is that by Garcia and Montaldo (1971), although the group at the University of Bahia is studying the responses of cassava to irrigation.

Improved Information Systems

Until recently it has been difficult to track down the literature dealing with cassava, although in the past few years there have been several special bibliographies (Montaldo 1967; Hermann 1968; Henain and Cenoz 1969; Ingram 1969; Anon. 1972*c*), in addition to some reports with lengthy lists of references (Grace 1971; Hendershott et al. 1971). However, none of these bibliographies appears to include more than about half of the world literature, which is currently believed to exceed 3000 references. An effort is being made to fill this void by preparing a comprehensive bibliography with a key word index and abstract of each item referenced (Monge 1973). A cassava thesaurus has been prepared (Leatherdale 1973) and the bibliography is expected to be published at the end of 1974. At that time, CIAT will institute a cassava information centre that will be linked into FAO's AGRIS network and will be able to provide selective bibliographies, abstracts, and photocopies of the world literature to interested workers.

In recent years the literature on cassava has grown by about 50 documents each year. The last 2 years have seen a remarkable upsurge in these numbers, particularly in 1973, due especially to two meetings, the Third International Symposium on Tropical Root Crops (48 papers) and the cassava toxicity meeting (18 papers). In this paper I have mentioned the names of close to 100 scientists who are actively engaged in research on cassava at the present time.

This is a big change from the situation only 3 years ago. However, if the world really produces almost 100 million tons of cassava a year, and if this has a farm value that is normally at least US $10 per ton, as my figures suggest, we are talking of a commodity whose annual production value exceeds $1000 million dollars and may reach $1.5 billion. As far as I can judge, the research devoted to the production side of this industry lies between $2 and $3 million per year, or perhaps 0.25% of the value of production with maybe 40% of the research funding going to CIAT and related programs.

In human resource terms, there appear to be less than 10 trained geneticists working full time on this crop, with an even smaller number of physiologists and economists. The state of knowledge described in this paper and some of the questions raised suggest that the current research input may still be too low, especially in terms of the value of the crop and its apparent growth potential. Areas requiring more research are numerous but perhaps most important of all is to ensure that more work is performed on an interdisciplinary basis. One has only to study the literature to recognize how limited the breadth of past research on cassava has been and how irrelevant are many of its findings. Hopefully, with the network of cassava researchers and the information services that are developing, we shall not see these past mistakes repeated.

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