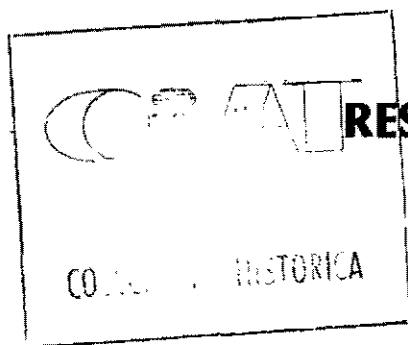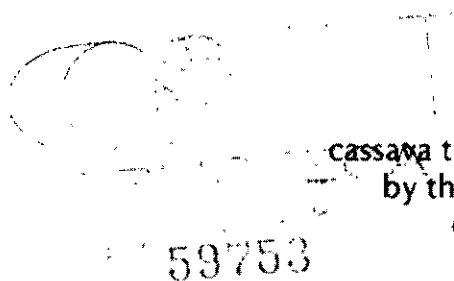# CASSAVA :

## RESEARCH, PRODUCTION AND UTILIZATION

# CASSAVA PROGRAM

Material used in the
cassava training courses offered
by the Centro Internacional
de Agricultura Tropical

Preliminary edition
by J.H. Cock and J.A. Reyes

UNDP

CIAT

**1985**

# CONTENTS

III

CHAPTER V: PROCESSING AND UTILIZATION                              653

# FOREWORD

Cassava is the fourth major calorie source produced in the tropica for human nutrition, and its demand here has grown in recent years. In spite of its importance, cassava has received little attention in the general development policies and research and extension programs in most of the tropical countries.

In 1971, the Centro Internacional de Agricultura Tropical, CIAT, initiated a large integrated effort to develop cassava research and training for professionals in national institutions. Throughout these years, the Cassava Program developed a preliminary cassava production manual containing the most recent research developments; the dynamics of this research process has not allowed the publication of this manual in a formal manner. However, the continuous demand for the most recent information by participants in the first courses, universities, research and extension institutions, private industries and farmers, has encouraged us to publish the manual.

It is important to emphasize that the papers included in this manual provide no complete answers to all problems and questions regarding cassava production.

This work is not yet finished in a final text, but the most updated research concepts and results are recorded here. Because of the growing information generated from new research results, we will be forced in the future to revise this publication periodically in order to update the information with progress in cassava research and production in Latin America.

James H. Cock
Coordinator
Cassava Program

# INTRODUCTION

The growing demand for cassava in tropical areas has encouraged the establishment of research and training programs for professionals in countries interested in producing and using this important energy source. As a result of the interest for this crop, the need emerges to disseminate the available information and the latest research results.

This compilation of scientific papers was first published in 1976 and has been revised every 2 years to add the most recent information produced by the efforts of the CIAT cassava team members. After three unpublished versions we are now distributing and excellent edition with the main purpose of complementing the cassava research, production and utilization training courses given at CIAT, to facilitate the implementation of cassava programs in tropical countries of Latin America.

This publication is divided into chapters in a sequential order leading the reader first through the morphological and physiological aspects of the plant and the potential of the crop for the utilization of the energy resources before an indepth study of breeding aspects that will provide the researchers with knowledge on the best combinations to make the most efficient use of the enormous genetic variability available.

Other chapter presents the agronomic and management practice by which excellent yields can be obtained. Since cassava is generally planted in low fertility soils and its greatest expansion potential is in tropical marginal areas, these cultural practices are recommendation that can be easily applied for the benefit fo the farmer, without increasing production costs.

With this same approach, is described the most important pests and diseases attacking the cassava plant and the management practices required for the crop to reach its maximum potential without the deleterious effect of pests and diseases on production and without the application of expensive inputs for control.

The utilization section of the program is the one most recently created. However, progresses obtained provides alternatives to overcome the bottleneck that the high perishability of the roots create for their utilization in energetic, human and animal nutrition. The use of cassava meal in balanced diets is most common in Europe but not well known in the re-

gions where cassava could be an excellent production alternative.

All the papers have been carefully studied for the ease of the readers, but preserving the style of each one of the authors; at the end of most of the papers an extensive bibliography is included for those interested in more detailed aspects of specific topics.

# CASSAVA: A BASIC ENERGY SOURCE IN THE TROPICS[1]

James H. Cock*

## ABSTRACTS

Cassava (*Manihot esculenta*) is the fourth most important source of food energy in the tropics.  More than two-thirds of the total production of this crop is used as food for humans, with lesser amounts being used for animal feed and industrial purposes.  The ingestion of high levels of cassava has been associated with chronic cyanide toxicity in parts of Africa, but this appears to be related to inadequate processing of the root and poor overall nutrition.  Although cassava is not a complete food it is important as a cheap source of calories. The crop has a high yield potential under good conditions, and compared to other crops it excels under suboptimal conditions, thus offering the possibility of using marginal land to increase total agricultural production.  Breeding programs that bring together germ plasm from different regions coupled with improved agronomic practices can markedly increase yields.  The future demand for fresh cassava may depend on improved storage methods.  The markets for cassava as a substitute for cereal flours in bakery products and as an energy source in animal feed rations are likely to expand.  The use of cassava as a source of ethanol for fuel depends on finding an efficient source of energy for distillation or an improved method of separating ethanol from water.

## INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is a perennial vegetative propagated shrub grown throughout the  lowland tropics for its starchy, thickened roots  the fresh  roots  of  cassava contain    20 to 40 percent dry matter and have a starch content that approximates 85 percent of the dry matter.   In developed countries, where it is a foodstuff of minor importance, cassava

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is commonly known only in ther forms of tapioca, starch pearls or flakes, or as a component of animal rations. In developing countries, however, it is a major food staple. After rice, maize, and sugarcane, cassava is the fourth most important dietary source of calories produced within the tropics (Table 1).

Cassava has long been a basic staple. There is direct evidence of its cultivation 2500 years ago and circumstancial evidence that the crop may have been cultivated for 4000 years in the Americas. It has been suggested that many areas now under tropical rainforest were once cultivated with cassava and corn in shifting culture. On the arrival of the conquistadores from the Old World, cassava was found throughout the lowland tropics of the Americas and the Caribbean. The cassava was either eaten after boiling or was rasped, after which the toxic juices were eliminated by squeezing the mask in basket-weave tubes (known as a *tipiti* in Brazil) and the remaining mash was roasted to a meal. Cassava production appears to have decreased after the arrival of the conquistadores, when the population of lowland areas was decimated by introduced diseases.

With the opening up of trade between Africa and Brazil by the Portuguese, cassava was taken to the Congo Basin in the 16th century. Two centuries later the crop was independently introduced to Madagascar and the east coast of Africa from where it was taken inland and rapidly became established as a basic staple.

The introduction of cassava to Asia is not well documented, but he plant was problably taken to the Philippines in the Manila galleon from Acapulco, Mexico, in the 17th century. It was already grown in Indonesia by 1740, and it was probably introduced by the Portuguese to Goa somewhat earlier. By the end of the 19th century the crop was dispersed throughout lowland tropical Asia and the islands of Oceania.

In the 20th century cassava production has continued to expand throughout the lowland tropics, mainly on the less-fertile, poor-quality agricultural lands. In Africa the capacity of cassava to grow and yield well on low-fertility soils, its ability to withstand locus attacks and drought, and its low cost of production have provided the economic incentive to use it as a replacement for other traditional root crops such as yams. In areas of Africa where population growth has caused a reduction of the rotation pattern in shifting culture and a commensurate decline in soil fertility, cassava is one of the few crops that can sill be successfully grown provided some form of rotation remains. Similarly in southern India and Java, as population has increased, cassava has increasingly been grown as a basic dietary staple on low quality land that is not suitable for rice production. In the 1970's the area planted to cassava in Thailand increased fivefold, mainly on the poorer,

2

TABLE 1. CALORIES PRODUCED FROM MAJOR STAPLES AND UTILIZED
FOR DIRECT HUMAN CONSUMPTION. THE DATA FOR TROPICAL
ZONES ARE COMPARED WITH THOSE FOR THE WORLD AND ARE
EXPRESSED AS BILLIONS OF KILOCALORIES PER DAY.

| Crop | Tropical zones | World |
|------|---------------|-------|
| Rice | 924 | 2043 |
| Sugar (cane and beet) | 311 | 926 |
| Maize | 307 | 600 |
| Cassava | 172 | 178 |
| Sorghum | 147 | 208 |
| Millet | 128 | 204 |
| Wheat | <100* | 1877 |
| White potatoes | 54 | 434 |
| Banana | 32 | 44 |
| Plantain | 30 | 30 |
| Sweet potatoes | 30 | 208 |

* Wheat figures are distorted by the fact that major produc-
tion zones in Brazil, Mexico, and India are outside the
tropics and have been adjusted to account for this.

unexploited land of the northeast.

## CASSAVA PRODUCTION

World cassava production for 1980 was estimated at 118 million tons, with 45 million tons in Africa, 41 million tons in the Far East, and 32 million tons in South America.  This is the energy equivalent of 40 to 50 million tons of cereal grains. The area harvested was 13.7 million hectares, with a mean yield of 8.7 tons per hectare (equivalent to 3 to 3.5 tons of grain per hectare).  During the last 20 years, total cassava production has increased at the same rate as population growth in developing countries.  This increase is largely due to increases in area planted, since yields have remained constant (Fig.1). The usual yield of about 9 tons per hectare is far below the maximum experimental yield of 80 tons per hectare in a 12-month growing season.  However, since most cassava is grown within traditional farming systems, with little or no use of fertilizers, fungicides, insecticides, herbicides, and irrigation, these yields compare favorably with those of other basic energy crops such as the cereals.  Although two grain crops can be harvested each year in some tropical areas, this is not possible in regions where there is a long dry season and irrigation is not feasible.  In these regions only one cereal crop can be produced or cassava can be grown.  With traditional management under these conditions, cereal yields are only 1 to 2 tons per hectare per year.

Cassava is produced mainly by small farmers, although there are a few large plantations.  Small farmers generally follow agronomic practices that do not depend on inputs normally associated with modern agriculture.  Planting material is derived from mature plant stem-cuttings, which sprout axillary buds 2 to 3 weeks after being placed in the soil.  The plant grows, becoming well established after 3 to 4 months when it begins to produce thickened roots.  The roots are generally harvested any time from 7 to 18 months after planting.  In some areas cassava is grown as a famine, reserve crop, and the plants are left until required.  Roots are harvested by pulling on the stem until the whole plant is uprooted (Fig.2).

## CASSAVA CONSUMPTION

Approximately 65 percent of the total cassava production in the period 1975 to 1977 was used for direct human consumption, about 21 percent for animal feed, and lesser amounts for starch and industrial use (Table 2).  Of the cassava used for human consumption about half is eaten after the fresh roots are

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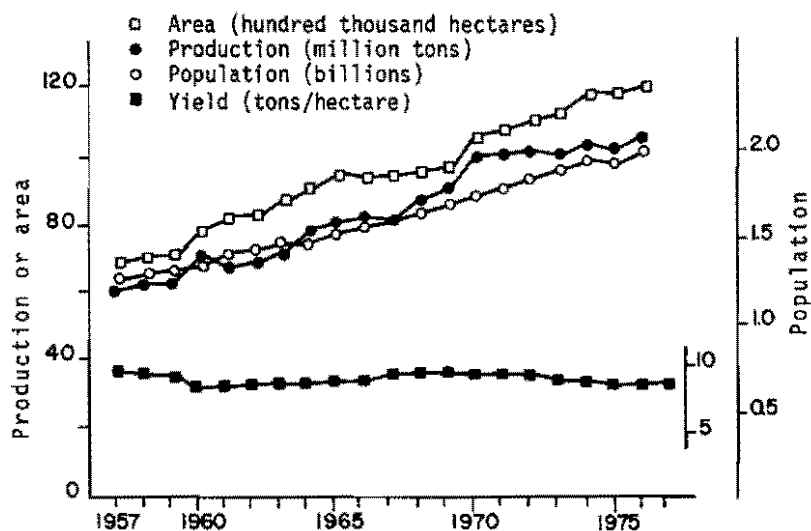
FIGURE 1. PRODUCTION, AREA, AND YIELD OF CASSAVA AND THE POPULATION OF THE DEVELOPING COUNTRIES WHERE ALMOST ALL CASSAVA IS GROWN.

FIGURE 2. CASSAVA TOPS ARE CUT OFF AND THE ROOTS DUG OUT
USING THE STUMP TO HELP UPROOT THEM.

TABLE 2.  WORLD CASSAVA UTILIZATION, 1975 TO 1977, AND ESTIMATED PRODUCTION IN 1980.

| Area | Production (million metric tons) | Human food (%) | Animal feed in developing countries-(%) | Industrial use and starch -(%) | Exports* (%) | Waste (%) | Stock changes (%) |
|------|------|------|------|------|------|------|------|
| Africa | 45.4 | 88.7 | 1.4 | † | † | 9.5 | † |
| Asia | 41.0 | 55.3 | 2.9 | 8.6 | 23.0 | 6.3 | 3.9‡ |
| Americas | 31.7 | 42.4 | 33.4 | 9.6 | † | 14.0 | † |
| World | 118.4 | 64.6 | 11.5 | 5.5 | 7.0 | 10.0 | 1.4 |

*    Largely animal feed used in developed countries.

†    Less than 1 percent

‡    Changes in stocks of dried cassava chips mainly in Thailand.

cooked, and the other half is processed in a number of different ways to make flours or meals. From FAO data it can be inferred that at present 450 million to 500 million people from 26 tropical countries consume approximately 300 kilocalories per day as cassava. These data probably overestimate the number of people consuming cassava and underestimate the per person calorie intake, since the data are based on country means. Highest per capita consumption levels occurs in Africa, with an estimated 50 million people consuming more than 500 Kcal/day, and in southern India, where approximately 25 million people consume over 700 Kcal/day.

There are many reports of chronic cyanide toxicity in regions of Africa where cassava consumption levels are high. Cyanide is liberated from root tissues, when they are damaged, by the action of linamarase on linamarin. Cassava clones which have a high cyanide content, and which are normally bitter to the taste, can cause acute cyanide poisoning if the roots are eaten without being processed. This type of poisoning is rare, however, and it is the long-term ingestion of low levels of cyanide from cassava that has more commonly been associated with goiter, cretinism, tropical ataxic neuropathy, and tropical diabetes. Cyanide is detoxified by the formation of thiocyanate from thiosulfate. Thiosulfate is formed from sulphur-containing amino acids, the presence of which is essential for detoxification. Cyanide decreases the concentrations of sulfur amino acids and increases the concentration of thiocyanate in the blood. Tropical ataxic neuropathy is associated with protein malnutrition and extremely low levels of sulfur amino acids in the blood. Thiocyanate inhibits thyroid uptake and iodine transport and is, thus, associated with goiter and cretinism.

Problems associated with cassava toxicity are not widespread outside western Africa, however, and occur only in areas where processing of the roots is rudimentary, dietary iodine levels are low, and the intake of protein and sulfur amino acids is suboptimal. Chronic cyanide toxicity is not reported in Kerala, southern India, where people consume more than 700 Kcal/day as cassava. Protein consumption in Kerala is low (37.8 to 41.5 grams per person per day),but the amino acid content of the protein is reasonably well balanced, with fish being a major component. This suggests that chronic cyanide toxicity need not occur when overall nutrition is adequate. This view is reinforced by recent work in Zaire by Ermans *et al*, showing that administration of slowly absorbable, iodized oil is a cheap and effective prophylactic for chronic cyanide toxicity and may be a more appropriate solution to the problem than trying to change the dietary staple.

The amount of cyanide in cassava can be greatly reduced by adequate processing. In areas of northeast Brazil, large amounts of farinha (a type of cassava flour) are consumed. During fa-

8

rinha production most of the cyanide is eliminated when the cassava mash is squeezed and the water, containing much of the cyanide, is discarded. More cyanide is eliminated when the resulting mash is roasted. There is no evidence of chronic cyanyde toxicity among the consumers of farinha.

Although cassava is of somewhat nutritional value, it is, at least in the dried form, among the least expensive available sources of calories (Table 3). While it is true that cassava is not a complete food, calorie deficiency is widespread in the developing countries. The International Food Policy Research Institute estimates that by 1985 some 1.5 billion people will suffer from malnutrition, which is highly correlated with calorie deficiency. It is here that the significance of cassava lies, in the nutrition of the poorer and most undernourished populations of the developing countries.

BIOLOGICAL POTENTIAL

Most cassava crops are grown between 30°N and 30°S, in areas where annual rainfall is greater than 750 millimeters and annual mean temperature is greater than 18° to 20°C. Small amounts of cassava are grown near the equator in South America and Africa at altitudes up to 2000 meters, under annual mean temperatures as low as 16° to 17°C, but with minimal seasonal fluctuations.

Cassava is potentially one of the most efficient crops in terms of starch production. Yields of 80 tons of fresh roots per hectare per year (29 tons of dry roots per hectare per year) have been obtained under optimum growing conditions but without supplementary irrigation. In areas with high rainfall, total radiation is reduced by cloud cover and yields of 30 tons of dry roots per hectare per year appear to be close to the theoretical yield limit. Several other crops, such as sugarcane, maize, sorghum, and rice have yield potentials of a similar order when one, two, or three crops are harvested per year; hence, in these situations, cassava has no great advantage over other crops.

The yield potential of cassava is not based on a particularly high photosynthetic rate of individual leaves nor on a high maximum rate of growth. For cassava, the maximum recorded level of these parameters are, in fact, much lower than the high rates for other major crops such as sorghum, maize, and sugarcane. Cassava has a relatively long, 9-month to 2-year growing season, and a remarkably high harvest index (ratio of weight of economically useful parts to total biomass production)(Table 4), and these two factors enable cassava to produce yields similar to, or greater than, other major crops under optimum conditions.

9

TABLE 3.  THE RELATIVE COST OF CALORIES FROM DRIED CASSAVA COMPARED WITH TWO
OTHER BASIC ENERGY STAPLES IN VARIOUS TROPICAL COUNTRIES.  THE DATA
ARE PRESENTED AS RELATIVE COST OF CASSAVA WITH COST OF COMPARED STA-
PLE FIXED AT 100.

| Compared crop | Location | Relative cassava cost | Year | Reference source |
|---|---|---|---|---|
| Rice | Kerala, India | 45 | 1970 - 1971 | (10) |
| Rice | Indonesia | 44 | 1976 | (12) |
| Maize | Indonesia | 76 | 1976 | (12) |
| Rice | Ghana | 31 to 55 | 1955 | (14) |
| Maize | Ghana | 75 to 89 | 1955 | (13) |
| Rice | Nigeria | 41 | 1973 | (13) |
| Maize | Nigeria | 93 | 1973 | (13) |
| Rice | Northeastern Brazil | 48 | 1975 | (15) |
| Maize | Northeastern Brazil | 57 | 1975 | (15) |

It is, however, under suboptimal conditions that the yield potential of cassava excels when compared with other crops.

## Yield Potential Under Suboptimal Conditions

Crops grown in many tropical areas suffer from uncertain rainfall, long dry periods, and soils with low pH, high aluminium concentrations, and low fertility. In the 1960's the strategy of the Green Revolution to increase agricultural production was largely directed at removing these constraints through the use of irrigation, soil amendments, and fertilizer applications, and by combining the improved agricultural conditions with plant varieties capable of exploting them. Since those halcyon days, high energy cost has made it necessary to search for crops and farming systems that are per se tolerant of adverse conditions and that have the capacity for an acceptable degree of productivity under a regimen of low inputs. The characteristics of cassava are in line with this new perspective.

In many tropical areas where there are Oxisols and Ultisols, heavy lime applications must be made to increase pH and reduce toxic aluminium levels in the soil. In the acid infertile eastern plains of Colombia, cassava gave acceptable yields without liming, whereas other crops tested, with the exception of cowpea, yielded essentially nothing (Fig. 3 ). Cassava's tolerance for high aluminium concentrations and low pH has been unequivocally demonstrated.

At the University of Queensland, the nutritional requirements of cassava have been studied in nutrient solution. For maximum growth, cassava's requirements for nitrogen, potassium, and calcium are similar to other crops, but its phosphorus requirements in nutrient solution or sterilized soil are somewhat higher. However, with the exception of phosphorus, the reduction in growth at low nutrient levels is much less in cassava, suggesting that the crop is highly tolerant of low nutrient levels. In soils where mycorrhizal infection occurs, the phosphorus requirements of cassava are somewhat low (Fig.4). Thus, under natural conditions with low nutrient levels, cassava can yield nearer its potential total biomass than most other food crops. This picture looks even brighter when economic yield is considered. Under nutrient stress the proportion of total dry matter production diverted to the roots is greatly increased in the more vigorous clones, such as MMex 59 (Table 4). The reduction in starch yield of these clones under nutrient stress is much less, proportionately, than the reduction in total biomass production. In anthropomorphic terms, it can be said that when cassava is under a tight budget system, it spends very wisely.

The tendency of cassava to increase the distribution of

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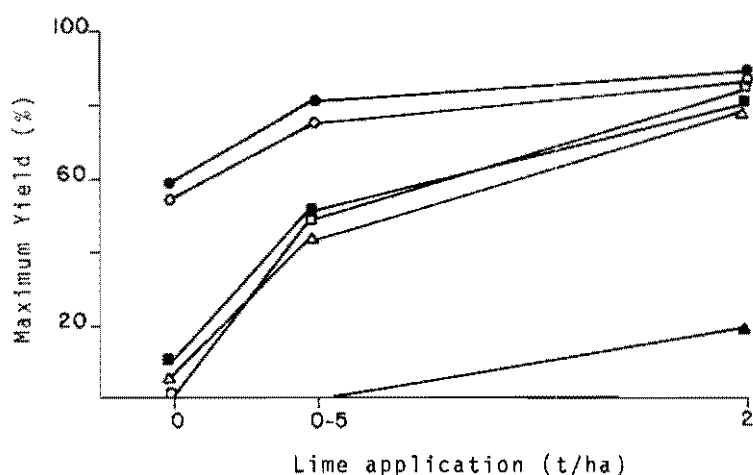
FIGURE 3. RESPONSE OF CASSAVA(●), COWPEA (○), RICE (■), CORN (□), BLACK BEANS (△), AND NONBLACK BEANS (▲) TO LIME ON AN ACID INFERTILE OXISOL IN THE EASTERN PLAINS OF COLOMBIA. DATA PRESENTED AT PERCENTAGE OF MAXIMUM YIELD OBTAINED BY EACH SPECIES WITH 6 TONS OF LIME APPLIED PER HECTARE.
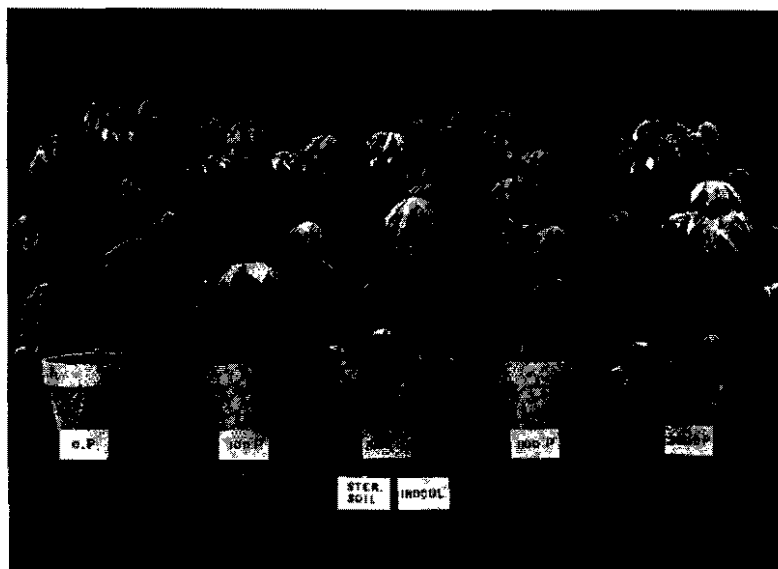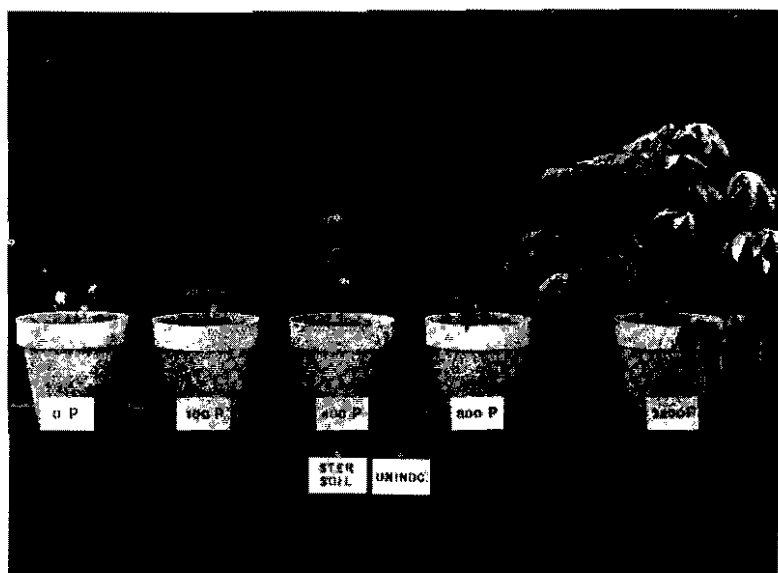
FIGURE 4.    ON A STERILIZED SOIL WITH LOW PHOSPHORUS LEVELS UP
TO THE EQUIVALENT OF 3200 Kg OF PHOSPHORUS MUST BE
APPLIED PER HECTARE FOR MAXIMUM GROWTH (TOP),
WHEREAS PLANTS INOCULATED WITH MYCORRHIZA GROW WELL
WITH NO APPLIED PHOSPHORUS (BOTTOM).

TABLE 4.  EFFECTS OF SOIL FERTILITY LEVELS ON
THE HARVEST INDEX OF 9 MONTH OLD CA-
SSAVA.  THE HARVEST INDEX IS THE DRY
WEIGHT OF ROOTS DIVIDED BY THE TOTAL
PLANT DRY WEIGHT.

|          | Fertility level | | |
|----------|------|--------|------|
|          | High | Medium | Low  |
| MCol 22  | 0.80 | 0.81   | 0.81 |
| MMex 59  | 0.46 | 0.56   | 0.74 |
| CMC 40   | 0.68 | 0.71   | 0.68 |

biomass to the roots also occurs under water stress.  This effect was so marked in one trial that plots of the clone (stressed for 2 months), in spite of reduced total dry matter production, yielded more roots at final harvest than unstressed plants. During drought stress cassava follows a conservative pattern of water use, closing its stomata and reducing the formation of new leaves.  Leaves that remain on the plant have a remarkable ability to actively photosynthesize when moisture becomes available.  Thus, the plant slows its growth during drought periods but rapidly recovers when they cease.  Unlike many other crops, cassava, once established, has no critical period when drought will cause a disastrous decrease in yield (Fig. 5).  Hence, cassava is well adapted to areas that experience a long dry season or uncertain rainfall.

In traditional growing areas, the native cassava clones tend to be resistant to the disease and pest complexes of the region.  Clones from the eastern plains of Colombia are usually resistant to cassava bacterial blight, superelongation disease, and anthracnose, which are endemic in this area, but are susceptible to phoma leaf spots, which occur in cooler climates.  As with many other food crops, when cassava is introduced to new areas with initially low disease and pest pressures, diseases and pests that flourish in that environment may subsequently be introduced and cause severe yield losses.  This has undoubtedly occurred in the cases of the green spider mite in east Africa and mealy bugs in west Africa, where the recently introduced pests have caused great reductions in  yields.  Nevertheless, in the Americas it appears that over the centuries farmers have selected clones that are highly resistant to the diseases and pests prevalent in their cassava growing areas.  Biological control is often very effective for pests of cassava grown under traditional management practices.


BREEDING FOR INCREASE YIELD


The ability of cassava to survive low inputs and water stress and its demonstrated resistance to pests and diseases make this crop a leading candidate for low-input agricultural systems.  Nevertheless, world mean yields for cassava are far below the yield potential.  A major question is whether it is possible, through breeding, to obtain clones that are able to approach the demonstrated yield potential and maintain it over a number of years, even under marginal conditions.

Although farmers have already selected lines of cassava that give high yields under local cassava-growing conditions, they probably have not exploited the true yield potential of the crop.  More than likely there is a degree of inbreeding depression in their selections.  Furthermore in traditional slash

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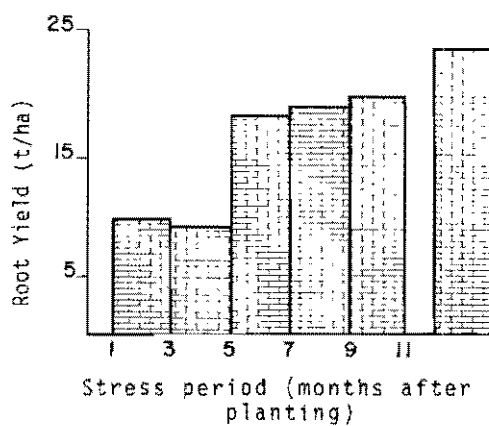
FIGURE 5. YIELD OF CASSAVA WITH WATER
STRESS AT DIFFERENT GROWTH
STAGES

and burn culture, cassava is normally widely spaced and planted with other crops. Under these conditions selection may well be for yield per plant rather than for yield per hectare. There is evidence that yield per plant of segregating populations is negatively related to yield per unit area under dense planting. Highly vegetative plants that produce a large number of cutting tend to have a low harvest index, which tends to be reduced further in dense stands; while at the same time vegetative cutting quality may also be reduced. Thus, when there is no conscious selection for high harvest index, selection may actually be for lower harvest index and, hence, for reduced yield potential.

A major factor causing reduced or unstable fields in cassava is the complex of diseases and pests that attack the crop. Although farmers have selected varieties that are relatively tolerant of diseases and pests, they have had relatively limited gene pools and a limited number of seedlings from which to select broad-based, tolerant types. It is now possible to bring together many clones representing a broad genetic base from different areas. Through breeding programs large numbers of crosses can be obtained, thus increasing the probability that higher yielding, disease- and pest resistant clones can be selected. The results of breeding programs at the International Institute for Tropical Agriculture (IITA) in Africa and the Centro Internacional de Agricultura Tropical (CIAT) in South America suggest that this is indeed the case.

## AGRONOMIC CONSIDERATIONS

Large improvements in yield will probably not be obtained solely by charging the clones grown but will also require concomitant modifications in agronomic practice. Farm surveys in Colombia, Ecuador, Nigeria, and Thailand have shown that yields may be reduced because of diseases and pests, poor quality of planting material, mixed cropping, poor agronomic practices, and low soil fertility.

Diseases and pests may both limit current crop yields and reduce the quantity and quality of the planting material for the next crop. Apart from host-plant resistance, several practices can lead to improved vegetative cutting quality. Careful selection of planting material and pesticide treatment can greatly reduce germination losses and initial levels of infection. Once a plantation is established there are many pathogens and insect pests that may attack it and cause severe yield losses. Frequently, a farmer's first reaction to an insect attack on cassava is to apply a potent insecticide. This may lead to the destruction of beneficial insects and result in repeated attacks. In some instances effective biological controls have been developed. For example, a biological control for the hornworm (*Erynnyis ello*) is in commercial use. Sometimes much simpler control

17

methods can be effective. For example, root rots, which are common in high rainfall areas, can be greatly reduced by crop rotation and by planting on ridges or mounds, as is traditional in Africa, India, and northeastern Brazil. Other examples could be given, but the few shown here illustrate that when host-plant resistance is not available, diseases and pests can often be controlled without resorting to chemical products.

Disease and pest incidence is usually reduced when cassava is intercropped. Cassava yields per hectare in mixed cropping are normally less than when cassava is the sole crop. Yield reduction is even greater when the cropping association is with vigorous, long-season crops. The slow, early establishment of cassava makes it possible to intercrop cassava with crops that have a short growth cycle, such as beans and cowpeas, with minimal competition and yield loss. It is more efficient to grow cassava intercropped with such legumes than to grow the root crop and the legumes separately in monoculture. Hence, although mixed cropping reduces cassava yield, the total food production per hectare is often enhanced. It is for this reason that much of the world's cassava is grown intercropped.

In traditional shifting culture cassava is grown with other crops. Cassava often becomes more important towards the end of the cropping cycle because of its ability to grow on depleted soils. This, however, has led to two misconceptions: first that cassava depletes the soil, and second that cassava does not require fertilization. Depleted soils that will not support other crops will often still support an economic yield of cassava, but to do this will become further depleted. Hence cassava gains the reputation of a crop that depletes the soil. In fact, nutrient extraction per ton of dry matter harvested is no greater for cassava than for other crops (Table 5) and, with the exception of potassium, cassava actually depletes the soil less than most other crops when nutrient extraction per unit of dry matter produced is considered. Nevertheless, in order to obtain high cassava yields on infertile soils, fertilization is required.

CIAT has established regional trials of cassava growth at sites that vary for climatic, edaphic, and biotic conditions, to compare the best available, low-input agronomic practices with traditional practices. These trials have shown that in Colombia, where the national average cassava yield is close to 10 tons per hectare, yields of the best local clones could be doubled by simple improvements of management practices (not including irrigation). If new high-yielding clones were included, yields could be tripled to more than 30 tons per hectare. These agronomic practices with high yielding clones have been field tested on poor soils by farmers with a very low resources base. The yield levels of a small farmer using good management practices were slightly greater than those obtained in the regional trials (Table 6). These data suggest that cassava yields could

TABLE 5. SOIL NUTRIENTS EXTRACTED BY STARCH STAPLE CROPS. THE DATA ARE EXPRESSED AS KILOGRAMS NUTRIENT EXTRACTED PER TON OF DRY MATTER HARVESTED.

| Crop | Nitrogen | Phosphorus | Potassium |
|------|----------|------------|-----------|
| Cassava (roots) | 6 | 1 | 11 |
| Maize (grain plus cob) | 21 | 5 | 6 |
| Rice (grain plus hulls) | 13 | 3 | 4 |
| Potatoes (tubers) | 10 | 2 | 22 |

TABLE 6.   YIELD COMPARISON BETWEEN SCIENTIST-MANAGED CASSAVA
          TRIALS AND FARMER-MANAGED TRIALS.   YIELDS ARE EXPRES-
          SED AS TONS OF FRESH ROOTS PER HECTARE

| Clone | Regional trial | Good farmer | Poor farmer |
|-------|----------------|-------------|-------------|
| Traditional technology | | | |
| Secundina | | 10.0 | 6.1 |
| CM 342-170 | | 20.5 | 9.6 |
| Improved technology* | | | |
| Secundina | 12.6 | 16.5 | 10.5 |
| CM 342-170 | 20.8 | 21.4 | 19.7 |

*   Unirrigated with no fertilizer application

be greatly increased at the farm levels by using good agronomic
practices and the best local varieties.  These yields could be
further increased by the introduction of better adapted, higher
yielding clones.

     Before a new technology reaches farmers it should be tested and
adapted to specific local conditions and practices by national pro-
grams.  However, national research expenditure on cassava is ex-
tremely low in comparison with other starchy staples (Table 7).
Returns on investment in agricultural research are generally
high and it would seem a priori that a crop such as cassava that
has received so little attention from the scientific community
should be no exception.  One might even expect that, with a crop
that has not been intensively researched, the returns could be
greater than with most other crops.  This viewpoint is reinforc-
ed by data from Cuba where threefold increases in yields have
been obtained over a 5-year period as a direct result of an in-
tensive research effort.

TABLE 7.  NATIONAL EXPENDITURE ON AGRICULTURAL RESEARCH FOR VARIOUS STARCHY STAPLES.

| Commodity | Gross value of production in developing countries 1972 (US.$ billion) | Research expenditure in national program 1971 (US.$ million) | National expenditure as percent of gross value of product |
|---|---|---|---|
| Sorghum | 1.5 | 12.2 | 0.77 |
| Maize | 3.0 to 4.0 | 29.6 | 0.75 |
| White potatoes | 1.0 | 8.2 | 0.68 |
| Wheat | 5.0 to 6.0 | 35.9 | 0.65 |
| Sugarcane | 5.0 to 6.0 | 30.2 | 0.50 |
| Rice | Over 13.0 | 34.7 | 0.26* |
| Sweet potatoes | 3.0 to 4.0 | 3.4 | 0.09 |
| Cassava | 5.0 to 6.0 | 4.0 | 0.07 |

*   Shallow water rice 0.40

## PRESENT DEMAND AND FUTURE POTENTIAL USE

### Fresh Cassava

About half of the current cassava production is destined
for fresh consumption, which is much greater in rural than in
urban areas.  The low level of urban consumption is a reflec-
tion of the high perishability of fresh cassava and the high
marketing margins that result in high urban consumer cost.  If
the urban price of fresh cassava could be lowered, the urban
consumption might increase.  This possibility is supported by
the fact that in the lower income strata the income elasticity
of demand for fresh cassava is high in countries such as Ghana,
Indonesia, and Brazil.  Costs can be reduced in part by improv-
ed production technology aimed at lowering the "farm gate" cas-
sava price, and also by improved storage techniques that redu-
ce both the risks of transporting and of bulk purchasing and,
thus, reduce marketing margins.

Cassava is a difficult crop to handle in the postharvest
period.  Roots start to deteriorate 1 to 7 days after they are
harvested.  Initial physiological deterioration is later com-
pounded by microbial action.  Physiological deterioration can
be controlled by preharvest leaf prunning or by packing freshly
harvested roots in polyethylene bags.  Fungicide treatments help
to control the microbial deterioration.  Problems associated
with quality changes under storage and possible toxic fungicide
effects remain, but economical solutions to extending cassava
shelf life could yet result in reduced consumer cost and increas-
ed urban demand.

### Dried Cassava

At low-income levels demand for fresh cassava is strong,
but as income rises, demand flattens off.  Dried cassava con-
sumption for the lowest income strata tends to increase with
increased income to a point, after which it declines.  Never-
theless, currently and in the near future it is precisely those
people in the lower income groups who consume the greatest
amounts of cassava flour and are likely to be the major benefi-
ciaries of increased production and lower costs.  As countries
develop and incomes rise it is likely that, in the short-term,
consumption of dried cassava will increase slightly but that in
the long run the consumption level will decline.

At the same time it is expected that demand for bakery pro-
ducts from wheat flour will increase rapidly.  Few lowland, tro-
pical, developing countries can meet the present demand for
wheat flour from their own production, and increasing demand
leads to ever increasing wheat imports.  In order to satisfy
urban demand for affordable bakery products, many national go-

vernments and aid agencies heavily subsidize locally produced and imported wheat. These subsidies make it difficult for wheat flour substitutes to compete and, hence, may prevent the development of local alternatives. It is technically feasible to substitute wheat flour with 10 to 20 percent cassava flour, yet this rarely occurs. This is partly because of the wheat subsidy and partly because of the lack of supplies of dried cassava flour. If, however, a reasonable price structure were to exist for wheat flour substitutes, it appears that cassava produced with the use of modern technology could be an attractive alternative.


## Feed Market

Before cassava becomes a major component of bakery products it is likely to enter into the feed grain market as an energy source, as has already occurred in Europe. During the last 20 years developing countries have markedly increased their feed concentrate demand. This demand, which is particularly high for poultry rations, has thus far been met partly through increased local agricultural production and partly through grain imports. Direct competition between grain for human consumption and grain for feed concentrate occurs in some areas, heightening food supply problems. In addition, cereal grain importation has done little to create employment and nothing to develop local agriculture, while adding to the severe drain in foreign exchange.

In Europe cassava pellets are used as an energy component in balanced poultry, pig, and dairy rations. In the last 10 years cassava pellets exports from Thailand to the European Economic Community have increased from less than 1 million to as much as 6 million tons per year. While these figures amply demonstrate the feasibility of incorporating cassava in animal rations, the Thai case is exceptional. Thailand is one of the few developing countries that exports grain, and the Thais do not eat much cassava. Nevertheless, cassava production could be increased for use as animal feed within other countries that are at present net importers of food grains. Recent studies in Ecuador and Colombia suggest that if yields can be raised to 15 tons per hectare per year, cassava will become highly competitive in the feed grain market. In recent years Mexico has faced steeply increasing grain deficits. To reduce grain imports a major program was implemented to produce cassava on underutilized lands. An interesting aspect of the Mexican plan is that cassava is being planted on land that is normally considered too poor for crop production, with the goal of increasing total agricultural production rather than increasing one commodity at the expense of another. This strategy should be directly applicable to many other tropical countries that have both cereal grain deficits and underutilized areas of poor soils.

## Energy

Dwindling fossil fuel supplies have resulted in renewed interest in alternative energy from biomass. Cassava is frequently mentioned as a potential biomass crop because of its ability to produce high yields of carbohydrates. These carbohydrates can be used to produce ethanol.

Brazil has vast areas of acid, infertile soils that are currently underutilized. It is in these areas that very small amounts of cassava are grown as a substrate for alcohol production. Locally grown tree crops are used to fire the boilers for anhydrous ethanol production. With this system net energy ratios (NER) are positive (Table 8). If, however, fossil fuels are used in the distillation, the NER is barely greater than one. This suggests that where liquid fuel is in short supply, and where sources of nonliquid energy such as coal are available, cassava may indeed have a role to play. In other areas the NER could be improved by using cassava stalks as an energy source in a manner similar to the use of sugarcane bagasse (Table 8), but this has not yet been achieved even on an experimental basis. With currently available technology, 70 percent of the energy used in alcohol production from cassava is used in the industrial process, mainly in the separation of alcohol from water. Until this requirement can be reduced, the benefits of using cassava for alcohol production are questionable. However, less conventional, more energy-efficient separation methods are being developed. These could radically alter the potential use of cassava in energy production.

TABLE 8.   NET ENERGY RATIO (NER) OF CASSAVA AND SUGARCANE ALCO-
           HOL WITH DIFFERENT FUEL SOURCES FOR THE INDUSTRIAL
           PROCESS.

| Substrate | Fuel for industrial process | NER |
|-----------|------------------------------|-----|
| Sugarcane | Bagasse | 8.06 |
| Cassava | Oil | 1.21 |
| Cassava | Firewood | 1.97 |
| Cassava | Sun-dried cassava stalks | 4.97 |

# CONCLUSIONS

Cassava is potentially one of the most efficient producers of the most efficient producers of carbohydrates under poor agricultural conditions. Average world yields of less than 10 tons per hectare remain below potential production levels. Production technology requiring low levels of purchased inputs but utilizing improved varieties could greatly increase yields obtained by farmers, even those with very limited resources.

Dried cassava is the cheapest energy source in large areas of the lowland tropics. If yields could be increased and prices reduced, its use by the very poor would increase. In many parts of Africa and in southern India, Java, and northwestern Brazil, large proportions of the populations have such limited resources that they are forced to depend on the least expensive available calorie source. Since these populations are expanding, the role of cassava in partially alleviating hunger must not be underestimated. In other areas, as incomes rise, the total per capita consumption of cassava will probably decrease slightly, with a shift occuring from consumption of the dried product to consumption of fresh cassava. Government policy changes that favor cassava use as a wheat flour substitute will be necessary to increase the demand for high-quality flour for use in bakery products.

The use of dried cassava in animal feed rations has a tremendous growth potential particularly in developing countries. Adoption of improved agronomic practices and high-yielding varieties could reduce costs to a level where cassava can compete with either imported or locally produced cereal grains. In the former case, foreign exchange could be saved and local industry stimulated, while in the latter case, cassava could be produced on land not used for cereal production, thus alleviating cereal grain deficits.

In spite of the emphasis on cassava alcohol production in Brazil, where economic circumstances are somewhat different from most other regions, present-day technology does not give very positive net energy gains. Nevertheless, cost reductions in making anhydrous alcohol will make cassava production more attractive as a renewable energy source.

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# CHAPTER I

## PHYSIOLOGY

## CASSAVA: PHYSIOLOGICAL BASIS

# CASSAVA: PHYSIOLOGICAL BASIS[1]

James H. Cock*

## INTRODUCTION

Cassava is a perennial shrub grown, mainly for its starchy roots, between 30°N and S latitude. Near the equator it is found growing at altitudes up to 2300 m, but the highest altitude at which it is found becomes progressively lower further from the equator. It is grown mainly on the poorer soils of the tropics where rainfall is greater than 750 mm per year. The duration of the crop depends on the growing conditions. The period between planting and harvest is short (9 months to 1 year) in hot areas and longer (up to 2 years) in cooler or drier regions.

Cassava is the fourth most important source of energy which is both produced and consumed in the tropics (Table 1). Approximately 65 percent of total production is used for human consumption; about 19 percent goes for animal food, either in the developing countries or as export to the European Economic Community; about 5 percent is for industrial use and the remainder is waste (FAO, 1980). Total world production was estimated at 118 million tonnes in 1980 with 45.4 million tonnes in Africa, 41.0 million tonnes in Asia and 30.7 million tonnes in South America. The average yield is approximately 8 t ha$^{-1}$.

Cassava is a new world crop, but the exact area of its original domestication is not known with certainty. There is a major centre of diversity of *Manihot* spp. in Brazil and a secondary centre in Mesoamerica. Renvoise (1973) suggests that sweet cassava may have been domesticated first in Mesoamerica and bitter cassava in northern South America. Sweet cassava tends to have a lower prussic acid content than bitter cassava, but there is no sharp discontinuity between sweet and bitter types.

By the time the Spanish arrived in the Americas cassava was grown throughout the lowland tropics in the region. Since

TABLE 1.   CALORIES PRODUCED FOR DIRECT HUMAN CONSUMP-
TION IN THE TROPICS

|  | Tropics | World |
|---|---|---|
| Rice | 924* | 2043 |
| Sugar (cane and beet) | 311 | 926 |
| Maize | 307 | 600 |
| Cassava | 172 | 178 |
| Sorghum | 147 | 208 |
| Millet | 128 | 204 |
| Wheat | <100 | 1877 |
| Potato | 54 | 434 |
| Banana | 32 | 44 |

*    Billion of calories per day
Source: Cock (1982)

then its cultivation has spread first to Africa and then to
Asia, and it is now more widely cultivated outside the hemisphe-
re of its origin than within it.  Cassava was first introduced
to the Congo basin as early as 1558 by the Portuguese and spread
rapidly through what is now Angola, Zaire, Congo and Gabon, and
later into West Africa.  Separate introductions were made to
the east coast of Africa and Madagascar in the eighteenth centu-
ry, after which it rapidly became a staple throughout the low-
land tropical areas (Jones, 1959).  Cassava was probably intro-
duced to Asia in the seventeenth century and it was grown in
Indonesia by 1740.  By the end of the nineteenth century it was
widely grown throughout the lowland areas of tropical Asia and
Oceania.

     Cassava (*Manihot esculenta* Crantz) is a member of the fa-
mily Euphorbiaceae, tribe Manihotae, subfamily Crotonoideae
(Viegas, 1976).  In the older literature it is referred to as
*M. utilissima*, *M. esculenta* is never found in the wild, it
exists only as a cultivated species, but there are a large num-
ber of wild *Manihot* spp. and cassava can be crossed readily with
many of them.  The only other species of economic importance is
*Manihot glaziovii*, Ceara rubber, which is used on a very limit-

ed scale for production of latex.

PROPAGATION

Cassava may be propagated either from stem cuttings or from true seed. Whilst all commercial plantings are from cuttings, propagation from true seed is important for breeding programmes. Little is known about the control of flowering in cassava and some clones have never been known to flower. It appears that cassava flowers best at moderate temperatures (approximately 24°C) and it has been suggested that forking, the form of branching (see Figure 1) which is related to flower initiation, is promoted by long days in some cultivars (Cunha and Conceicao,1975; Keating, 1981; J. Veltkamp, personal communication). When the apical meristem becomes reproductive, axillary buds develop to form branches. Flowers are borne on axillary racemes near ends of branches. Many of the flowers formed abort, but Cock and Rosas (1975) found that long days reduced flower abortion in some clones and promoted abortion in others. Keating (1981) observed better flower formation at day/night temperatures of 28/16°C than at 28/28°C.

At constant temperature, freshly harvested cassava seeds germinate most rapidly and the percentage germination is highest at 35° (Ellis and Roberts, 1979). For seeds that have been stored for some time, the optimum constant temperature for germination is lower but germination of both fresh and stored seed is best when the temperature alternates between 25 and 35°C (Ellis and Roberts, 1979). Soaking in hot water, scarification, and removal of the seed coat did not improve germination (Martin and Ruberté, 1976) and scarification may actually decrease it (Mendes, 1977). Red light and treatment with gibberellic acid (GA₃) both increase germination (Mendes, 1977).

Cassava stem cuttings from mature plants may be planted directly after they are cut or after storage. Cuttings to be stored are usually cut into lengths of 1 m or more and placed in the shade for up to 6 months. During this time axillary buds at the upper nodes sprout but the sprouted parts are usually discarded before planting. Stored cuttings produce fewer sprouts and the plants from those which do sprout are less vigorous and yield less than plants from fresh cuttings. Much of this difference is related to microbial infection of the stored material. However, cuttings treated with fungicide were comparable to fresh cuttings in terms of the proportion that sprouted and the time they took to do so. The yield of roots from treated cuttings was unaffected by storage, but the weight of tops decreased slightly as the duration of storage increased (Table 2). These results were obtained under good growing conditions and it is possible that in more adverse conditions the
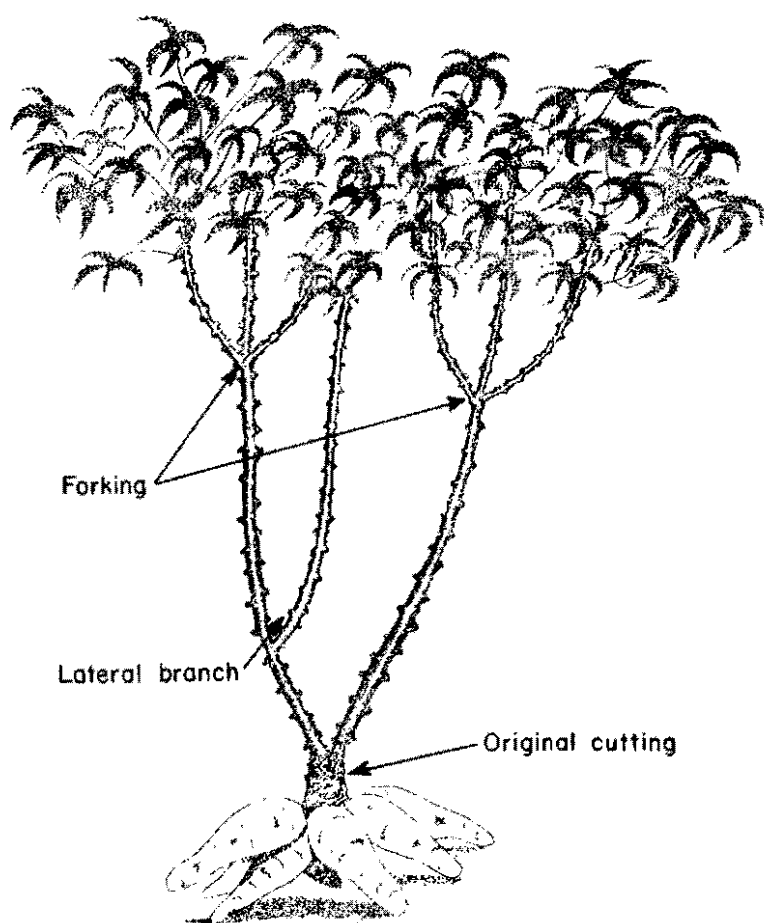
FIGURE 1

decreased vigour could result in lower yields from stored and
treated cuttings. The cuttings for commercial production are
commonly from 10 to 30 cm long and are taken from the woody
parts of mature plants. The axillary buds of green cuttings
will also develop, but they are more susceptible to fungal and
bacterial infection and are not used commercially. They may be
used for early multiplication of experimental materials or new
lines (Toro *et al*, 1982). Large cuttings give a larger initial
growth of shoots (Wholey, 1974), but this is not necessarily

TABLE 2.   EFFECTS OF STORAGE DURATION ON GROWTH AND YIELD OF
           CASSAVA.   CUTTINGS WERE TREATED WITH FUNGICIDES
           BEFORE STORAGE.

| Storage duration (day)s | Sprouting (%) | Weight of tops $(t\ ha^{-1})$ | Weight of roots $(t\ ha^{-1})$ |
|---|---|---|---|
| 0 | 100 a | 33 a* | 25 b |
| 60 | 100 a | 32 ab | 30 a |
| 120 | 100 a | 30 b | 24 b |
| 180 | 98 b | 29 b | 27 ab |

*   Means followed by the same letter are not significantly
    different.

Source: D. Leihner, CIAT, 1980.


correlated with final yield (Rosas, 1969).   The nutrient status
of cuttings influences their early development.   Cuttings taken
from plants grown on fertilized plots give better early growth
and the difference is sufficient to give larger yields when
these cuttings are planted in an infertile soil (Table 3).   The
rate of sprouting and the initial vigour of plants is dependent
on the variety used.   The physiological basis of these differ-
ences is not well understood, but Wholey (1974) suggested that
clones which produce more roots from the basal portion of the
stem, which tends to be in moister soil, may have more uniform
early growth.

     Sprouting is extremely sensitive to changes in temperatu-
res.   In two varieties only 20 percent of the cuttings sprouted
at 16 °C and sprouting was much delayed in all varieties at low-
er temperatures (Cock and Rosas, 1975).   Sprouts are produced
fastest between 28.5 and 30°C, but no sprouts were produced when
temperatures were increased to between 37 and 39°C or decreased
to between 12 and 17°C (Keating and Evenson, 1979).   Shoot growth
is greatest at 30 to 32°C (Wholey, 1974).

     Cassava cuttings may be planted vertically, inclined or ho-
rizontally.   After planting, most of the axillary buds on the
cutting being to develop, but growth of the shoots at the proxi-
mal end of the cutting suppresses development of the other buds
(Wholey, 1974).   Horizontally planted cuttings produce more
shoots, and the suppression of some shoots by others is less
pronounced.

37

TABLE 3.  EFFECTS OF FERTILIZATION OF MOTHER PLANTS USED FOR
STEM CUTTINGS, ON YIELD OF DAUGHTER PLANTS.

| Fertilizer treatment (kg ha$^{-1}$) | | | Fresh root yield of daughter plants (t ha$^{-1}$) |
|---|---|---|---|
| N | P | K | |
| 0 | 0 | 0 | 19.1 |
| 100 | 0 | 0 | 26.4 |
| 0 | 87 | 0 | 29.2 |
| 0 | 0 | 125 | 23.7 |
| 100 | 87 | 125 | 26.2 |

Selected data from R. Howeler, CIAT (1981)

GROWTH AND DEVELOPMENT

The shoot shows marked apical dominance and new leaves are
produced in sequence on the mainstem.  Once the apex becomes
reproductive, from one to six of the axillary buds (usually
only two or three) develop and produce the forking or branching
characteristics of cassava (Fig.1).  Lateral shoots ocassional-
ly develop from axillary buds on the lower part of the stem.
This form of branching is very common when plants lodge, which
suggests that apical dominance is dependent on the normally
erect position of the mainstem.

Leaf Anatomy and Photosynthesis

The cassava leaf has a single layer of palisade cells and
a dispersed, spongy mesophyll.  The vascular tissue in the spon-
gy mesophyll is surrounded by bundle sheath cells that contain
abundant chloroplasts, but in the palisade tissue bundle sheath
cells are absent (El-Sharkawy and Cock, unpublished).  Early re-
ports suggest that the cassava leaf has most stomata on the low-
er surface and very few on the upper surface (Tan, 1980; Perei-

38

ra, 1977; Connor and Palta, 1981). However, some clones have been found recently with significant numbers of stomata on the upper leaf surface (El-Sharkawy and Cock, unpublished). Stomatal density on the lower leaf surface is high (400 to 700 mm$^2$) compared with other crops (Pereira, 1977; Connor and Palta, 1981).

The phytosynthetic rate of cassava leaves and wild *Manihot* spp. in early measurements were of the order of 15 to 29 mg $CO_2$ dm$^{-2}$ h$^{-1}$ (Mahon *et al*, 1977) and 33 mg $CO_2$ dm$^{-2}$ h$^{-1}$ in the clone MCol 72 in other trials (CIAT, 1978). However, Tan (1980) obtained rates up to 45 mg dm$^{-2}$ h$^{-1}$ in MCol 72. More recently with improved techniques rates of over 40 mg $CO_2$ dm$^{-2}$ h$^{-1}$ have been obtained regularly (El-Sharkawy and Cock, unpublished). Mahon *et al* (1977) estimated the $CO_2$ compensation at 68 ppm and more recently El-Sharkawy and Cock (unpublished data) estimated it to be close to 50 ppm. These data indicate a C3 photosynthetic pathway, but Pereira (1977) has observed that the lack of light saturation is not typical of C3 photosynthesis and the existence of bundle sheath cells that contain many chloroplasts in the spongy mesohyll is also atypical.

The photosynthetic rate of individual leaves changes little with leaf age (Figure 2) and has a broad temperature optimum between 20 and 40 °C (El-Sharkawy and Cock, in press). Photosynthesis is extremely sensitive to differences in the leaf-to-air vapour pressure deficit (Figure 3). The decline in photosynthesis at high vapour pressure deficits appears to be a result of the closure of stomata in response to changes in leaf-to-air vapour pressure deficit.

The palmate cassava leaf blade is subtended by long petioles which are normally at least 50 percent longer than the central lobe of the leaf. The petioles appear to play an important role in orienting the leaves to intercept the maximum amount of light (El-Sharkawy and Cock, unpublished).

## Leaf Growth

At high temperatures (24°C or greater) the time from appearance to full expansion of a leaf is about two weeks. This period is greatly extended at lower temperatures (Cours, 1951). The size of fully expanded leaves increases with the age of the plant up to about 4 months and then declines; however, at low temperatures the maximum size is smaller and the largest leaves are produced later (Figure 4). The increase in size to a maximum and the subsequent decline is found in all cassava clones studies to date. There are large differences between varieties in the size of the biggest leaves. In some clones the area of the largest individual leaves is 800 cm$^2$. The leaf size is greatly reduced when water is withheld (Connor and Cock, 1981)

FIGURE 2.  PHOTOSYNTHETIC RATE OF LEAVES OF CASSAVA  VARIETY
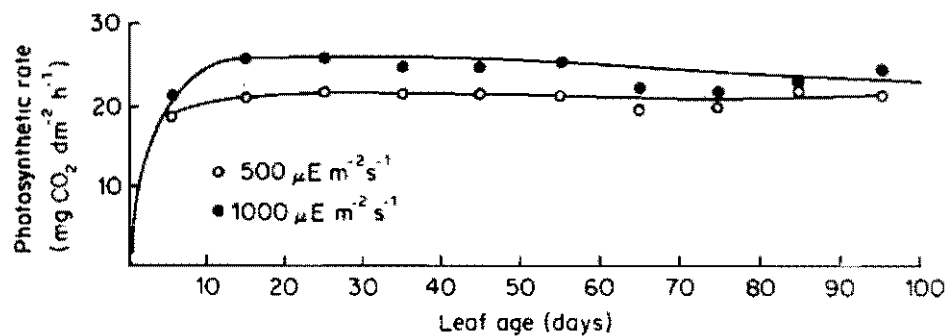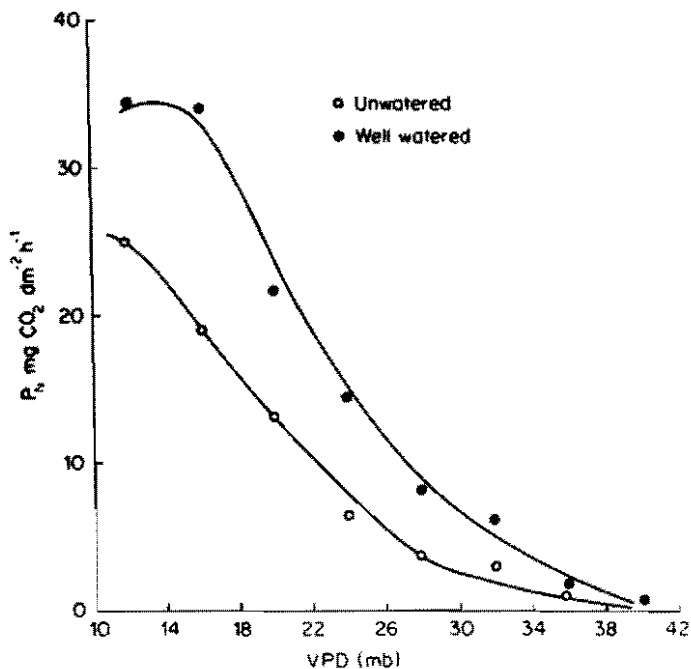MCOL 72 AT TWO LIGHT LEVELS.

FIGURE 3. THE EFFECTS OF VAPOUR PRESSURE DEFICIT
BETWEEN LEAF AND AIR ON NET PHOTOSYN-
THESIS ($P_N$) (cv. MCOL 90) OF INDIVIDUAL
LEAVES OF CASSAVA. (Source: El-Sharkawy
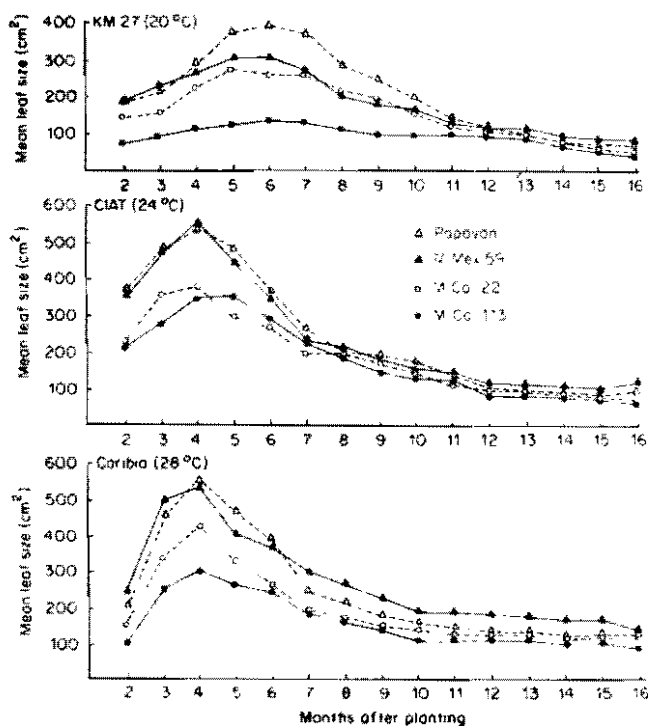and Cock, in press).

FIGURE 4.  LEAF SIZE OF FOUR VARIETIES AT DIFFERENT
TIMES AFTER PLANTING AT THREE LOCATIONS
WITH DIFFERENT TEMPERATURES (Source:
Irikura *et al*, 1979).

or the supply of nutrients is limited (CIAT, 1979, Parra and Cock, unpublished).

The life of individual leaves may be as long as 200 days at low temperatures (Irikura *et al*, 1979) and is commonly about 60 to 120 days. There is variation between varieties in the length of life of leaves (CIAT, 1978). It is a common belief that in dry periods cassava leaves fall, but this does not appear to be true.

In dry periods the total leaf are produced is smaller, but the life of individual leaves is not shorter (Connor and Cock, 1981). Leaf life is shortened by shading and in darkness all leaves fall within 10 days (Cock and Rosas, 1975; Cock *et al*, 1979). The effect of shading tends to limit the size of the leaf area developed, but in Queensland, Australia in long summer days with high solar radiation very high LAIs can be obtained (Keating, 1981). The abscission of the petiole induced by removal of the leaf lamina or by shading can be inhibited by applications of hormones (Cock and Rosas, 1975). The effect of long photoperiod and of high radiation may be to suppress the development of an abscission layer through a change in the hormone balance.

Stem Growth

Each nodal unit consists of a node, which subtends a leaf, and an internode. The rate of node production on each shoot decreases from approximately one node per day during early growth to about one node per week on plants one year old (Figure 5; Cock *et al*, 1979; Tan, 1980). There is little difference between varieties in the rate at which nodes are produced. However, in the unbranched clone MCol 72 the decrease with age in the rate of production of leaves on each apex is much less marked than in other clones (Tan and Cock, 1979b). Cooler temperatures reduce the rate of production of new leaves (Irikura *et al*, 1979; Keating, 1981) and long dry periods can almost completely suppress production (Connor and Cock, 1981). Individual nodes continue to increase in weight during growth (Figure 6) but the rate of increase is less in dry periods or when nutrients are limiting.

The total number of nodes per plant depends on the number of nodes per shoot and the number of shoots, or apices, per plant. Little is known about the control of branching or forking in cassava. Some clones will branch early and continue branching whilst others have never been known to branch. Under constant environmental conditions the interval between the formation of successive branches tends to be constant when the number of branches at each fork is small but increases when the branch number is large (Tan and Cock, 1979b; CIAT, 1979). Few-

43

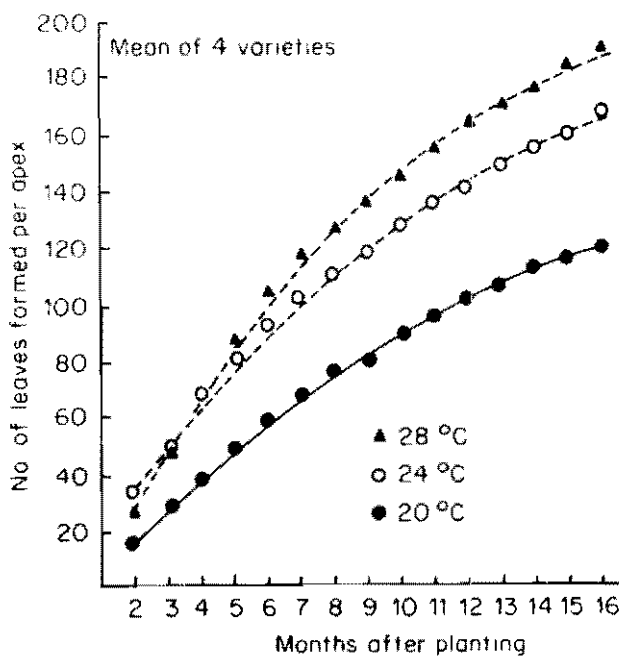FIGURE 5. CUMULATIVE NUMBER OF LEAVES FORMED PER APEX AT THREE DIFFERENT TEMPE-RATURES. (Source: Irikura *et al*, 1979).
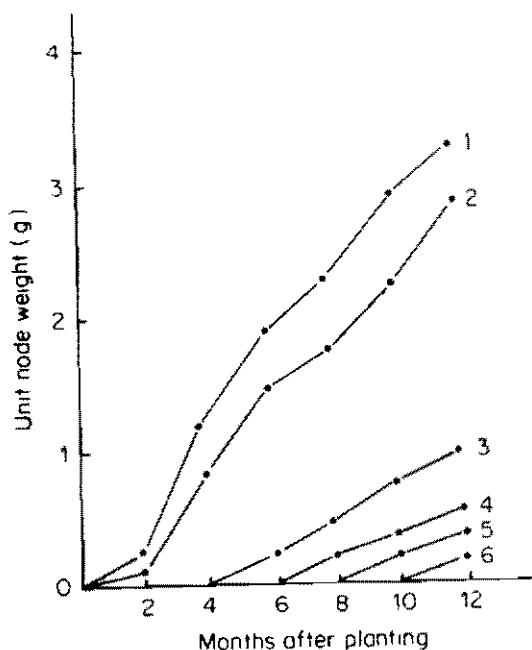
FIGURE 6. CHANGES WITH TIME IN THE WEIGHT OF
INDIVIDUAL NODES AT DIFFERENT LEVELS
IN THE CANOPY (Tan and Cock, 1979b).
NUMBERS AT RIGHT HAND SIDE ARE CANOPY
LEVELS, MEASURED IN INTERVALS OF 20
NODES ON THE MAINSTEM, OR WHERE BRANCHES
ARISE WHEN THERE ARE MORE THAN 40 NODES
BETWEEN BRANCHES.

er forks are produced at low fertility, particularly by plant
types that normally branch profusely (CIAT, 1979). The inter-
val between forking is also increased by water stress during
the growth cycle (Connor and Cock, 1981). The effects of tem-
perature on forking are not well understood; cool temperatures
delay the time to formation of the first fork and increase the
interval between successive forks, but in some clones the num-
ber of branches at each fork increases (Irikura *et al*, 1979).
At high temperatures (28°C and above) forking is decreased (Iri-
kura *et al*, 1979; Keating, 1981). In long photoperiods plants
fork sooner (Keating, 1981; J. Veltkamp, personal communica-
tion), and the total number of active apices is greatly increas-
ed.


## Root Growth

The main storage organs of cassava are the thickened roots.
As early as 28 days after planting large numbers of starch gra-
nules can be found in the xylem parenchyma of the parenchyma of
the fibrous roots and anatomically it is not possible to distin-
guish at this stage between roots that will later thicken and
those that will remain as fibrous roots (Lopez, 1976; Keating,
1981). From about 6 weeks after planting some of the fibrous
roots begin to thicken rapidly, laying down large quantities of
xylem parenchyma that are packed with starch granules. The
number of roots that will eventually thicken is determined ear-
ly in the growth with little change in the number of thick roots
in most varieties from 2 to 3 months after planting. There does
not appear to be any specific trigger to root thickening, such
as photoperiod. It has been suggested that root thickening be-
gins when the supply of carbohydrate exceeds the requirement
for growth of the stems and leaves (Cock *et al*, 1979; Tan and
Cock, 1979a).


## Growth Analysis

The leaf area of cassava depends on the rate of formation
of leaves, the size of the individual leaves and their longev-
ity. In single stem non-branching types leaf area index (LAI)
increases in the first 4 to 6 months as the number of leaves
and leaf sizes increases. Thereafter as leaf size and rate of
leaf production decrease and leaves die, the LAI declines.
This decrease in leaf area is partly offset in branching plants
by an increase in the number of apical meristems that produce
leaves. Except for the very large LAI values of 10 or more ob-
tained by Keating (1981) in the long, summer days in Queensland,
the largest LAI values recorded are about 6 to 7 (Cours, 1951;
Cock, 1976; Enyi, 1972, 1973). Crop growth rate increases with
LAI, to a LAI of about 4. With moderate levels of solar radia-
tion crop growth rates will then reach about 120 g $m^{-2}$ $wk^{-1}$

46

(Figure 7; cf., sweet potato, Hahn and Hozyo, Chapter 16 of
this volume). Higher rates (140 g m$^{-2}$ wk$^{-1}$) have been obtain-
ed where there is a very high solar radiation and long days.
In these circumstances CGR increased up to the highest LAI ob-
tained with no evidence of a ceiling LAI (Keating, 1981).

The cassava crop has simultaneous development of leaf area
and the economically useful part of the roots. This simultane-
ous development contrasts strongly with that of the cereal crops
where there is phasic development in which first of all the leaf
grains, are filled. In phasic development there is little com-
petition for the substrates used for growth of the photosynthe
tic and the storage organs. However, in cassava the current
supply of assimilate is partitioned between growth of leaves
and roots. This means there is an optimum leaf area index for
root growth; if partitioning unduly favours leaf growth then
there is less assimilate available for root growth; conversely,
too little leaf growth will limit photosynthesis and crop growth
rate and this in turn will limit yield (Figure 8). Manipulation
of this balance opens the way to obtaining high yields of cassa-
va.


YIELD IMPROVEMENT


Physiological Limits

Maximum crop growth rates of cassava within the tropics
are of the order of 120 g m$^{-2}$ wk$^{-1}$. Higher rates may be attain-
able eventually, but for the present this has been used as the
upper limit on productivity in a computer simulation model (Cock
*et al*, 1979) to predict yields of cassava varieties which differ
in morphological characteristics. The model predicts that
yields of about 30 t ha$^{-1}$ yr$^{-1}$ of dry roots are attainable.
Recently at CIAT yields of 28 t ha$^{-1}$ yr$^{-1}$ have been obtained
(CIAT, 1979). Some of the features of the type of plant that
will produce these yields are: the largest leaves should not
be less than 500 cm$^2$; first branches should be produced 6 months
after planting; and the life of individual leaves should be more
than 100 days (Cock *et al*, 1979). Such a plant gives an optimum
balance between leaf area and root growth when planted at a po-
pulation that gives 20,000 shoots per hectare. Given the rela-
tion observed between crop growth rates and leaf area index,
there appear at first to be two ways to increase yields. The
first would be to reduce the weight of the individual nodes and
hence the weight of the shoot. However, when the weight of the
node and internode was reduced by a factor of three in the su-
mulation model, it had only minor effects on the predicted
yield. Furthermore, such a change would be difficult to make
if leaf size is to be maintained, since Tan (1980) found little
difference between varieties in the ration of leaf area to node
weight; small nodes were associated with small leaves. The pe-
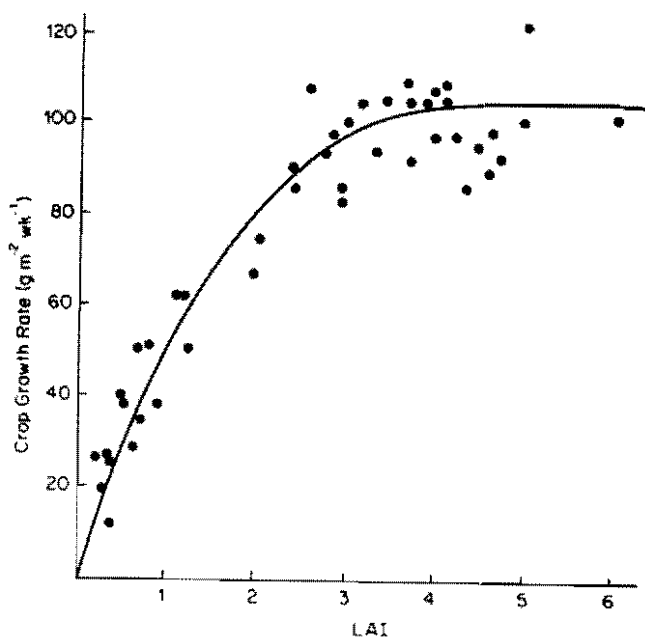
47

FIGURE 7.  CROP GROWTH RATE OF CASSAVA AS A FUNCTION
OF LAI IN VALLE, COLOMBIA.  RESULTS ARE
FROM SEVERAL TRIALS.  RADIATION LEVELS 400
TO 450 g cal $cm^2$ $day^{-1}$ AVERAGE (Source:
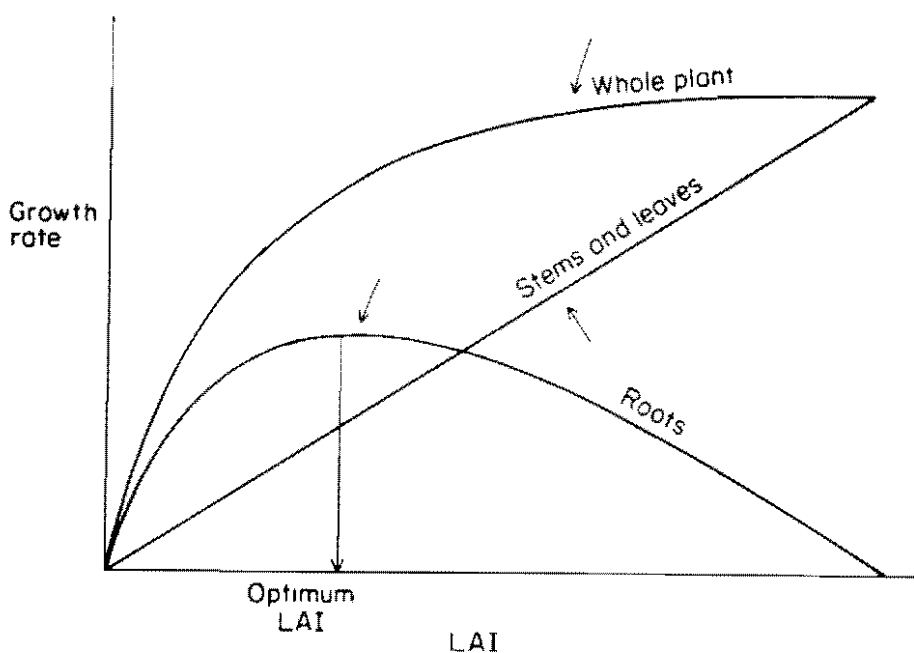Cock (in press)).

48

FIGURE 8. SCHEMATIC REPRESENTATION SHOWING RELATION
BETWEEN WHOLE PLANT GROWTH, PARTITIONING
OF GROWTH BETWEEN STEM (AND LEAVES) OR
ROOTS, AND THE OPTIMUM LAI FOR ROOT GROWTH.

tiole is about one-third of the total leaf weight and hence sessile leaves, which are known to exist, could reduce the dry weight of leaves. However, petioles play an important role in orienting leaves to intercept more sunlight at low and intermediate LAIs and hence it is doubtful whether sessile leaves would offer any advantage or whether they might even reduce yield. The second option would be to increase leaf life even further and reduce the dry matter required to maintain leaf area. The simulation model does suggest that this approach could further increase yields (Figure 9(a)), but it may be difficult to keep leaves healthy and free of insects for such long periods. Also such a strategy would imply a very low rate of leaf formation so that recuperation after defoliation would be slow.

This suggests that the main opportunity to increase yield, other than changes in morphology, is to increase crop growth per unit leaf area index. At a high leaf area index, crop growth rate can be increased by a more vertical orientation of the leaves, but there are good theoretical reasons to believe that at smaller LAIs that are near the optimum for root growth, there would be little advantage (Duncan $et$ $al$, 1967). It is worth noting that little difference in crop growth rate has been found in clones with a more erect leaf display (Cock, 1976). Perhaps the most promising approach therefore is to increase the photosynthetic rate of individual leaves. This approach has not been very successful in other crops, but it is known that C4 crops with high photosynthetic rates have consistently greater crop growth rates than C3 crops (Monteith, 1978). There is perhaps a better prospect with cassava than with many other crops of improving crop growth rate by increasing the photosynthetic rate of individual leaves. Cassava leaves, at least of some clones, have the ability to maintain photosynthesis at near maximum rates for a long time, and there is little evidence of sink limitations to photosynthetic rate. Furthermore storage in roots occurs when the leaves are photosynthetically active, not as photosynthesis is declining with age, as it is in some crops at the time storage organs are filling. Large differences in photosynthetic rate between clones are known to occur (Mahon $et$ $al$, 1977; CIAT, 1978; Tan, 1980; Cock and El-Sharkawy, unpublished), but up to the present they have not been related to differences in crop growth rate in the field. Increased crop growth rate would increase root yield in percentage terms approximately twice as much as the increase in crop growth rate and would also increase the optimum LAI (Figure 9(b)). In spite of this, the principal aim of efforts to improve cassava is not at present to obtain the highest possible yield in favourable environments, but rather to obtain stable yields in marginal conditions, where most cassava is presently grown and where its production is likely to expand in the future.
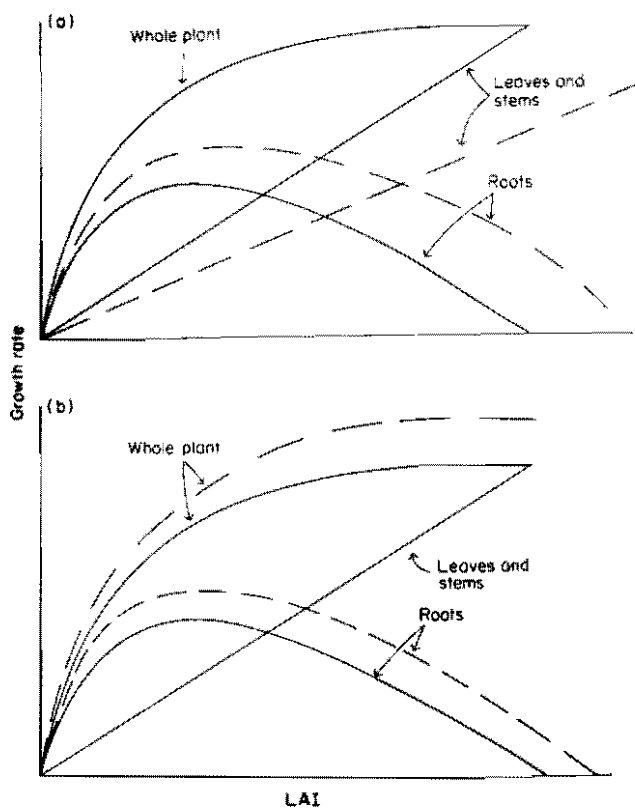
FIGURE 9. SCHEMATIC REPRESENTATION TO SHOW: (a) THE
EFFECT OF LONGER LEAF LIFE (DASHED LINES)
ON THE PARTITIONING OF GROWTH BETWEEN STEM
(AND LEAVES) AND ROOTS; (b) THE EFFECT OF
INCREASE IN CROP GROWTH RATE, FROM INCREASE
IN PHOTOSYNTHETIC EFFICIENCY OF LEAVES, ON
GROWTH OR ROOTS.

YIELD STABILITY


        The more variable the conditions in which a crop is grown
the greater will be the variation in its growth and yield.  In
agricultural systems where there is intensive management some
of this variation can be controlled.  For example, with inten-
sive management, rice cultivated in Japan is exposed to little
variation in water availability, fertility, and disease and
pest attack because these factors are controlled by irrigation
and the application of fertilizers and pesticides.  Cassava on
the other hand is usually in systems where there is little con-
trol of often unfavourable environments.  It is subject to the
uncertainty of rainfall, to variation in soil fertility and the
attack of diseases and pests during its long growth cycle.  Va-
riation in yield is correspondingly greater than it is in more
favourable, managed environments.  Farmers in many tropical en-
vironments have few resources with which to control changes in
the environment and they have developed cropping systems and
selected varieties which help ensure consistent yields from one
season to another.  The farmer is mainly worried about stabil-
ity from year to year (temporal stability); he is not usually
concerned with stability of the yield over large geographic a-
reas (spatial stability) although he may be interested in stab-
ility  of yield in different cropping systems (system stabil-
ity).

        Unlike the farmer, plant breeders are concerned with spa-
tial stability because the new varieties they develop must be
useful over large areas if a reasonable return on investment in
research and breeding is to be obtained.  The major factors af-
fecting yield stability are temperature, photoperiod, availab-
ility of water and nutrients, and diseases and pests.


Temperature and Photoperiod

        There is a marked genotype and temperature interaction on
field yield of cassava (Irikura $et$ $al$, 1979).  As temperature
decreases leaf area development becomes slower because fewer
leaves are produced at each apex and individual leaves are smal-
ler (Irikura $et$ $al$, 1979; Keating, 1981) but leaf life is incr-
eased (Irikura $et$ $al$, 1979).  Both Irikura $et$ $al$ (1979) and
Keating (1981) present data showing that forking increases with
temperature up to a certain level but is inhibited at higher
temperatures (e.g., 28°C and above).  The combined effect of
these factors on leaf development is that LAI tends to increase
with mean temperatures up to about 24°C and then reaches a
plateau.  Dry matter production also increases with temperature
but it may decline slightly at higher temperatures due to a de-

cline in net photosynthesis of leaves and high respiration (Keating, 1981). The trials of Irikura *et al* (1979) in constant temperatures suggest that at all temperatures a LAI of 3 is optimum for the maximum root weight increase and that this may be obtained by using varieties with vigorous top growth in cool temperatures and *vice versa*. The available data suggest that the phenotype of the ideal plant does not change with temperature but different genotypes are required in different temperature environments (Irikura *et al*, 1979). Cassava will not grow at temperatures below about 15°C.

The growth of cassava in a variable temperature environment is very different from growth at constant temperatures. In the field large seasonal differences in temperature are usually related to substantial changes in photoperiod. Keating (1981) studied cassava growth at 27°37'S latitude where there are large annual changes in temperature and photoperiod. In the summer period leaf and stem growth was profuse with LAIs of 10 or more. Forking was greatest in summer and this was shown to be due to a long photoperiod effect. Similar results were obtained by artificially lengthening photoperiod near the equator (J. Veltkamp, personal communication). Both high temperatures and long photoperiods decrease the proportion of dry matter passing to the roots (Irikura *et al*, 1979; Keating, 1981; J.Veltkamp, personal communication). It is still not clearly established whether this decrease is simply because a larger fraction of the assimilate goes to top growth or whether it is the result of hormone mediated effects on root development. Differences between varieties in sensitivity to daylength and the effects of this on root yield have been reported (CIAT, 1981; J. Veltkamp, personal communication). All varieties tested showed an increase in the number of branches and a decrease in harvest index in long days (Table 4) which suggests that these varieties are sensitive. In some varieties the decrease in harvest index is balanced by increased crop growth resulting from increased LAI throughout the growth period.

In Keating's trials leaves were shed in winter and crop growth rates fell to near zero. At this time the content of starch in roots was at a maximum and this was considered to be the best harvest time. The total dry weight produced in these conditions (30 t ha-1 yr-1) was less than the 40 t ha-1 yr-1 obtained nearer to the equator (Cock, in press). The reason is that in Kerating's experiment, although crop growth rates are high in summer total yield potential is reduced by the low growth rates in winter.

It appears that it is possible to find clones that do well in environments with nearly constant temperatures and photoperiod and also in fluctuating temperatures and photoperiods. The clone "Mantiqueira" produced at the Instituto Agronomico de Campinas, Sao Paulo, Brazil, very close to the tropic of Capricorn, has

TABLE 4. CHARACTERISTICS OF THREE CASSAVA CLONES HARVESTED 272
DAYS AFTER PLANTING AND GROWN UNDER NATURAL AND 16
HOUR DAYLENGTH.

| | | Total dry matter* (t ha-1) | Dry root yield (t ha-1) | Apices/ plant | Harvest index |
|---|---|---|---|---|---|
| MCol 1684 | Natural | 15.8 | 8.7 | 15 | 0.55 |
| | 16 hour | 16.4 | 4.6 | 81 | 0.28 |
| MPtr 26 | Natural | 13.9 | 8.1 | 8 | 0.58 |
| | 16 hour | 14.2 | 4.9 | 21 | 0.35 |
| MCol 22 | Natural | 14.3 | 9.5 | 13 | 0.66 |
| | 16 hour | 18.8 | 8.3 | 51 | 0.44 |

\*   Includes fallen leaves

Source: J. Veltkamp, part of work for Ph.D Thesis, Univer-
sity of Wageningen.


performed well througout the tropical areas of the Americas,
but other clones have shown much narrower adaptation. This ma-
kes it necessary to think in terms of separate selection for
areas with pronounced changes in temperature and photoperiod
during the year.


Water Stress

Cassava is grown in areas with as little as 750 mm rainfall
per year and it survives in areas with dry periods of 5 to 6
months. The crop has an extremely conservative pattern of wa-
ter use. At the onset of a dry period the production of new
leaves is reduced. This coupled with a very sparse root system
rapidly reduces the transpiration of the crop (Connor *et al*,
1981). The stomata close rapidly when the leaf is exposed to
dry air. The response is very marked in previously stressed
plants (Connor and Palta, 1981; El-Sharkawy and Cock, unpublish-
ed) and serves to limit water use at times when potential evapo-
transpiration is greatest. The reduced leaf area and stomatal
closure markedly reduce crop growth rates during periods of
stress (Connor *et al*, 1981). The heliotropic response of the
leaves offsets this to some extent and allows the plant to in-
crease light interception and hence photosynthesis early in the

early in the morning and late in the afternoon when potential evapotranspiration is low. Also a separate mechanism causes leaves to droop and so lowers the heat load on the leaves at midday (El-Sharkawy and Cock, unpublished). These mechanisms allow cassava to use the available water to best advantage.

The partitioning of dry matter to the roots is greatly increased in a drought period (Connor *et al*, 1981), particularly in normally leafy plants and hence the reduction in root yield is much less than that of total biomass (Table 5). The changes in dry matter distribution caused by a drought can persist even after the drought ends and for plants which normally have a high proportion of dry weight in tops may lead to a higher final yield than the yield from well watered controls (Connor *et al*, 1981). The yields of these vegetative vigorous forms are, however, still less than those from ideal plant types under good conditions.

TABLE 5.  PERCENTAGE OF TOTAL DRY WEIGHT INCREASE ACCOUNTED FOR BY THE ROOTS OF TWO VARIETIES DURING A PERIOD OF WATER STRESS AND IN A WELL WATERED CONTROL

| Variety | Stressed | Control |
|---------|----------|---------|
| MCol 59 | 53[a] | 32 |
| MCol 22 | 87 | 70 |

Source:  Connor *et al*, 1981

a(Root weight increase x 100) ÷ (total plant weight increase).

## Soils

Cassava grows remarkably well on poor soils. It will grow on extremely acid soils and give reasonable yields when most other crops would either fail or give very poor yields (Cock and Howeler, 1978) and it will tolerate very high levels of aluminium saturation (up to 80 percent) with no decrease in yield (CIAT, 1978). Although cassava tolerates acid soils it is extremely susceptible to salinity.

The requirements for potassium, nitrogen, and calcium are

TABLE 6.  THE EFFECT OF HIGH, MEDIUM, AND LOW FERTILITY LEVEL
ON LEAF AREA INDEX AND NUTRIENT CONTENT OF LEAVES +
PETIOLES OF MMex 59, 6 MONTHS AFTER PLANTING

| Fertility level | LAI | Nutrient content as % dry matter | | | Nutrient content as mg dm leaf surface | | |
|---|---|---|---|---|---|---|---|
| | | N | P | K | N | P | K |
| High | 5.39 | 3.69 | 0.25 | 2.00 | 18.9 | 1.28 | 10.3 |
| Medium | 3.54 | 3.68 | 0.19 | 1.40 | 20.2 | 1.04 | 7.7 |
| Low | 1.65 | 3.52 | 0.18 | 0.73 | 21.7 | 1.11 | 4.5 |

Source: Cock, J.H., and Parra G. (unpublished data)

similar to those for growth of other crops but, when the supply
of these nutrients is limited, growth is reduced less than in
most crops (Edwards *et al*, 1977).  Cassava requires more phos-
phorus than most other crops for maximum growth in solution cul-
ture (Edwards *et al*, 1977), but in the field the association
with mycorrhiza permits cassava to obtain its requirements in
soils that are low in phosphorus (CIAT, 1980).

On poor soils cassava maintains the nutrient content of
leaves by maintaining a smaller leaf area (Table 6).  This stra-
tegy leads to an efficienct use of nutrients to maintain crop
growth rate when limited amounts of nutrients are available
(Cock, in press).

When nutrients are limiting, total biomass production is
smaller but a larger proportion of the dry weight produced is
in storage roots (Cock, in press).  Hence not only is total
growth reduced less at low nutrient levels in cassava than other
crops, but also the reduction in root yield is less than the
reduction in total biomass production.

Cassava has no critical periods that markedly affect the
yield forming organs and hence may be more tolerant to disease
and pest attack than many other crops.  It is particularly to-
lerant of disease or pest attack that may reduce the number of
apical growing points, decrease the number of roots, or reduce
leaf size, but yields may be severely reduced by attacks that

reduce leaf life and photosynthetic rate (Cock, 1978). Many traditional varieties are very tolerant of defoliation but because they normally produce too much leaf they have a low yield potential (Figure 10). Data obtained by computer simulation suggest that new types with high yield potential are more sensitive to disease and pest damage and hence their yield potential may only be reached if it is coupled with increased disease and pest resistance (Cock, 1978).
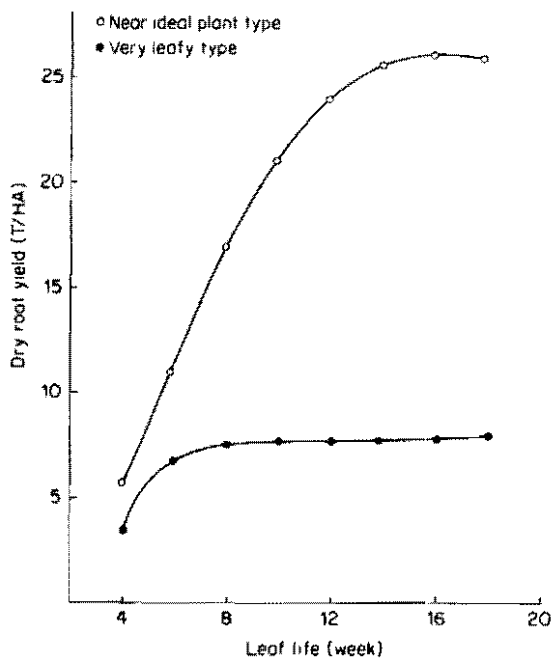
FIGURE 10.  COMPUTER SIMULATION OF THE EFFECTS OF
LENGTH OF LIFE OF INDIVIDUAL LEAVES ON
YIELD OF AN IDEAL PLANT AND A VERY LEAFY
PLANT TYPE.

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# CHAPTER II

## GERMPLASM AND BREEDING

CASSAVA GERMPLASM RESOURCES

HIBRIDIZATION AND BREEDING METHODOLOGIES APPROPRIATE
TO CASSAVA

INHERENT AND ENVIRONMENTAL FACTORS RELATED TO CASSA-
VA VARIETAL SELECTION

SELECTION FOR YIELD POTENTIAL

RAPID PROPAGATION TECHNIQUE FOR CASSAVA

CASSAVA TISSUE CULTURE

# CASSAVA GERMPLASM RESOURCES[1]

Clair H. Hershey*

## INTRODUCTION

Success in a crop breeding program depends on a wide array
of preconditions. Among the most basic of these is a thorough
understanding of the germplasm resources available. The basic
genetic diversity available to the breeder is normally the con-
sequence of natural selection over many centuries, added to more
recent farmer selection. The breeder must know where this vari-
ability exists, its characteristics, how to access it, and how
to utilize it in a productive breeding program. This set of
knowledge is generally placed in the category of "germplasm re-
sources", and includes the topics of origin and evolution, dis-
persal collection, conservation, evaluation, documentation and
utilization.

This paper will review only briefly the origin and early
dispersal of cassava, collection methods, and existing collec-
tions, as these aspects of cassava germplasm resources have been
adequately reviewed elsewhere (Byrne, 1984; Gulick *et al.* 1983;
León, 1977). The latter sections will look in more detail at e-
valuation and utilization of cassava germplasm, with an emphasis
on applied breeding aspects.

## ORIGIN AND EVOLUTION

The evolutionary history of cassava, like that of other root
and tuber crops, has been difficult to trace. Archeological re-
mains are rare for fleshy plant parts, and especially in the low-
land humid tropics. The most apparent and basic conclusion is
that cassava is a New World crop with origins in the lowland tro-
pics. Studies of processing artifacts from Colombia and Venezue-
la give evidence of cassava cultivation as early as 3000 to 7000
years ago (Rouse and Cruxent, 1963; Reichel-Dolmatoff, 1957; 1965).

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Recent reviews of the accumulated evidence have generally concluded multiple origins for cassava (Renvoize, 1973). Harlan (1971) has suggested cassava is non-centric, that is, with no obvious center of origin or of diversity. He also showed that areas of diversity need not correspond to centers of origin of a crop. Spath (1973) suggested four separate areas of origin: Guatemala and Mexico, the coastal savannas of northwestern South America, eastern Bolivia and northwestern Argentina, and eastern Brazil. Box (1982) postulates that high and low HCN types may have originated independently in meso and South America. The high HCN types were dispersed along the major rivers, while the low HCN types were found in drier areas (savannas). More recently, though, the low HCN types have spread throughout South America.

Based on extensive studies from Southern United States to Argentina, Rogers and Appan (1973) defined 98 species within the genus *Manihot*, widely distributed throughout the lowland tropics of the Americas. Nassar (1978) defined four centers of diversity of the wild species: central Brazil (southern Goia and western Minas Gerais) with 38 species; western Mexico with 19 species; and two lesser centers, one in northeast Brazil and the other in western Mato Grosso and eastern Bolivia (Fig.1). The three Brazilian centers have some species in common, most notably from the heterophylla section, which is closely related to the cultivated species (Rogers and Appan, 1973).

The groups of species from the northern and southern hemispheres are markedly distinct. With the exception of *Manihot esculenta*, none of the north american species are found naturally in South America, and only *Manihot brachyloba* occurs in both South and Central America.

Rogers and Appan (1973) hypothesize on the basis of taxonomic criteria that the genus *Manihot* is relatively recent in origin, and that in general the species are still rapidly evolving. There appear to be no sharp genetic delimitations among species. They are quite available with respect to vegetative structures, but relatively uniform in their floral organs.

The species of *Manihot* are perennial, and vary in form from acaulescent shrubs to trees with trunks of 25 cm diameter and a height of 10 to 12 m. They are generally sporadic in their distribution, and never become dominant members of the local vegetation. Most are encountered in dry regions, with few in rainforest ecosystems. Those found in rainforest areas are usually invaders after clearing of the forest. Thus, the species in *Manihot* appear to be shade-intolerant, capable of survival only with plenty of sunlight. They are not good competitors with vigorous intercrops or with weeds.

All the species are sensitive to frost, thus limiting their distribution to areas below about 2000 meters above sea level.

FIGURE 1. CENTERS OF DIVERSITY OF *MANIHOT* SPECIES
(Nassar, 1978).

Only two species (*Manihot grahami* and *Manihot anysophylla*) are
found in regions of occasional, but predictable,frosts.

As many of the species are found where long dry periods are
common, they have evolved mechanisms of drought avoidance or
drought tolerance.  One of the most notable of these mechanisms
is the production of storage roots  where large amounts of starch
are accumulated.  In all species studied, these storage roots
also contain the glucoside linamarin, which breaks down after
cell injury to release prussic acid (HCN).  The evolutionary sig-
nificance of HCN is not well understood.  Theories that it may
be associated with pest or disease resistance, or to higher yield
potential have not been confirmed by experimental results; how-
ever, resistance to rodents and other rooting mammals through HCN
production is likely.

Cassava appears to have evolved under highly localized bio-
logical and physical influences.  Due to wide early dispersal of
the crop and relatively low levels of genetic interchange among
regions, many distinct, locally adapted gene pools evolved.  Al-
though normally vegetatively propagated, cassava frecuently pro-
duces seeds which give rise to new variability in traditional
farming systems.  The plants derived from these seeds may be re-
cognized by farmers as being potential new varieties, and given
special care to compensate for their lower vigor at the initial
stages.  Thus, the farmer-breeder contributes to crop evolution.

Characterization of nearly 2000 cassava clones from Colombia
illustrates what has no doubt occurred throughout the american
tropics.  The CIAT collection was evaluated for a wide range of
traits, and then grouped according to area of origin of the clo-
nes within the country.  Figure 2 illustrates the patterns that
emerge for resistance to cassava bacterial blight, superelonga-
tion disease, green cassava mite, concentric ring leaf spot; and
for harvest index and root dry matter content.  Many other simi-
lar examples could be given.  The patterns that emerge for dis-
seaseand pest resistance closely correspond to their severity in a
region: where the problem exists, resistance has evolved; where
the problem does not exist, clones are generally susceptible.
High dry matter is a general characteristc of the north coast
clones, and to a lesser degree the Andean zone, where quality
for fresh consumption has been selected for over many years.
High harvest index is also typical of the clones of the north
coast region, which may be the result of evolution and selection
under cropping systems and cultural practices where a high compe-
titive ability (i.e., large top growth) was less essential than
in other regions.  Knowledge of these and other patterns of evo-
lution are critical to the efficient utilization of germplasm,
to be discussed later.

Figure 2. Classification of Colombian cassava germplasm for agronomic characteristics, by area of origin.
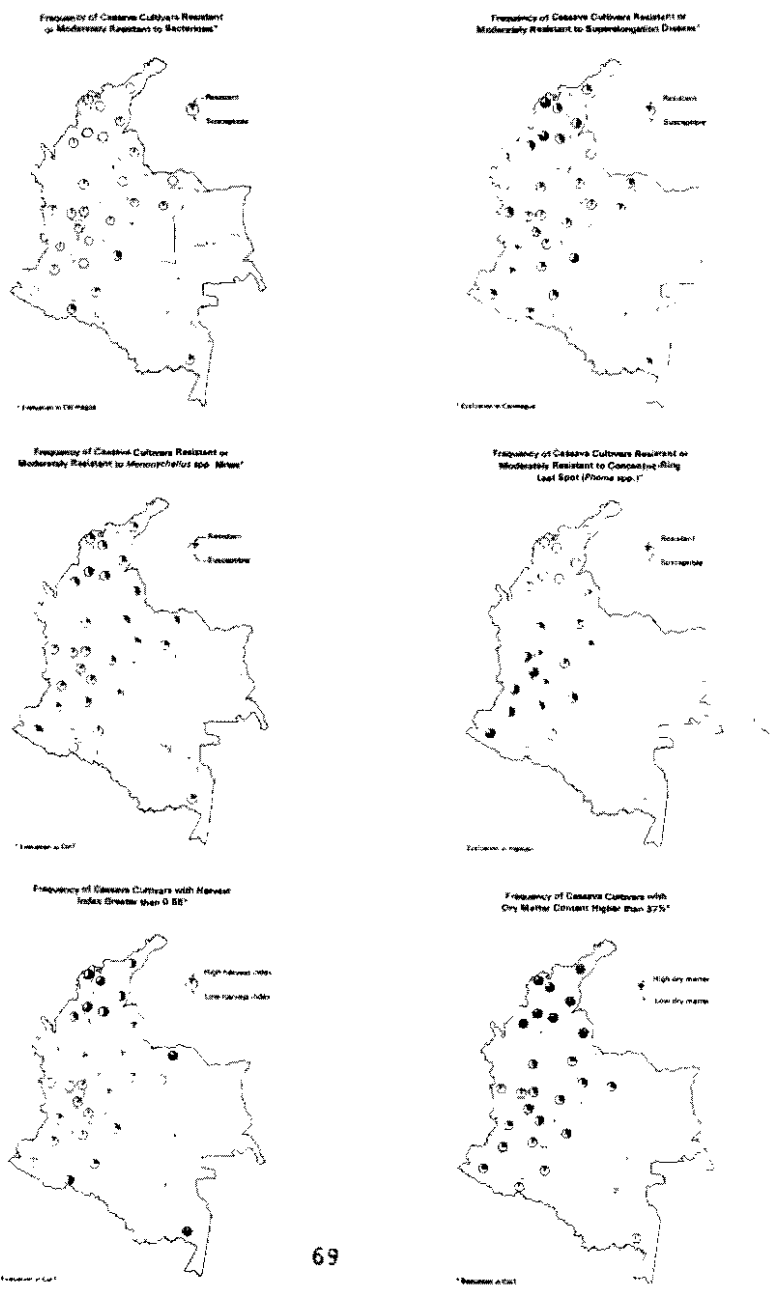
DISPERSAL


Cassava was widely distributed throughout the Americas and the Caribbean by the time of the arrival of the European colonists to the New World in the 15th century. First exportations were made from Brazil to west Africa by slave traders in the 1500s. Cassava may have been introduced to central Africa along trade routes from the Congo basin. An independent introduction was made by the Portuguese to east Africa, first to the island of Reunion in 1739, probably from there to Madagascar, and then to the mainland (Jones, 1959). The original introductions were very limited in terms of genetic diversity; nevertheless, in the slash and burn system widely practiced in the rainforest areas of Africa, it is likely that clones cross pollinated and superior seedlings were selected and multiplied to become new varieties. Thus, when Dr. Beck began a cassava improvement program in Nigeria in 1954, he was able to collect more than 450 morphologically distinct local cultivars (Beck, 1982). A similar range of diversity has been found by other workers in Africa. Thus, although the number of clones introduced to Africa was apparently small, the high heterozygocity of these clones resulted in the possibility for good local selection for a range of conditions.

Early introductions to Asia are less well documented than those to Africa. One of the first introductions was apparently from Mexico to the Philippines in the 17th century, with later introduction to Indonesia and the Asian mainland. Introductions were probably made to India from east Africa sometime in the 19th century. With the establishment of breeding programs in South America, Africa and Asia in the mid 1900s to present the distribution among regions has accelerated.


COLLECTION


The systematic collection of cassava germplasm did not begin until the mid 1900s, and then only on a regional basis. The first large international collections were assembled only recently, with the largest of these now held at the Centro Internacional de Agricultura Tropical (CIAT) in Cali, Colombia. Collection of cassava germplasm has been almost strictly based on collection of vegetative material.

An IBPGR (International Board for Plant Genetic Resources) working group on cassava, with representatives from Latin America, Africa and Asia, recently defined collection priorities in cassava and wild *Manihot* species, with emphasis on the centers of diversity in Latin America (Figs.3 and 4). Collection in Asia and Africa may be less urgent due to the lesser genetic va-
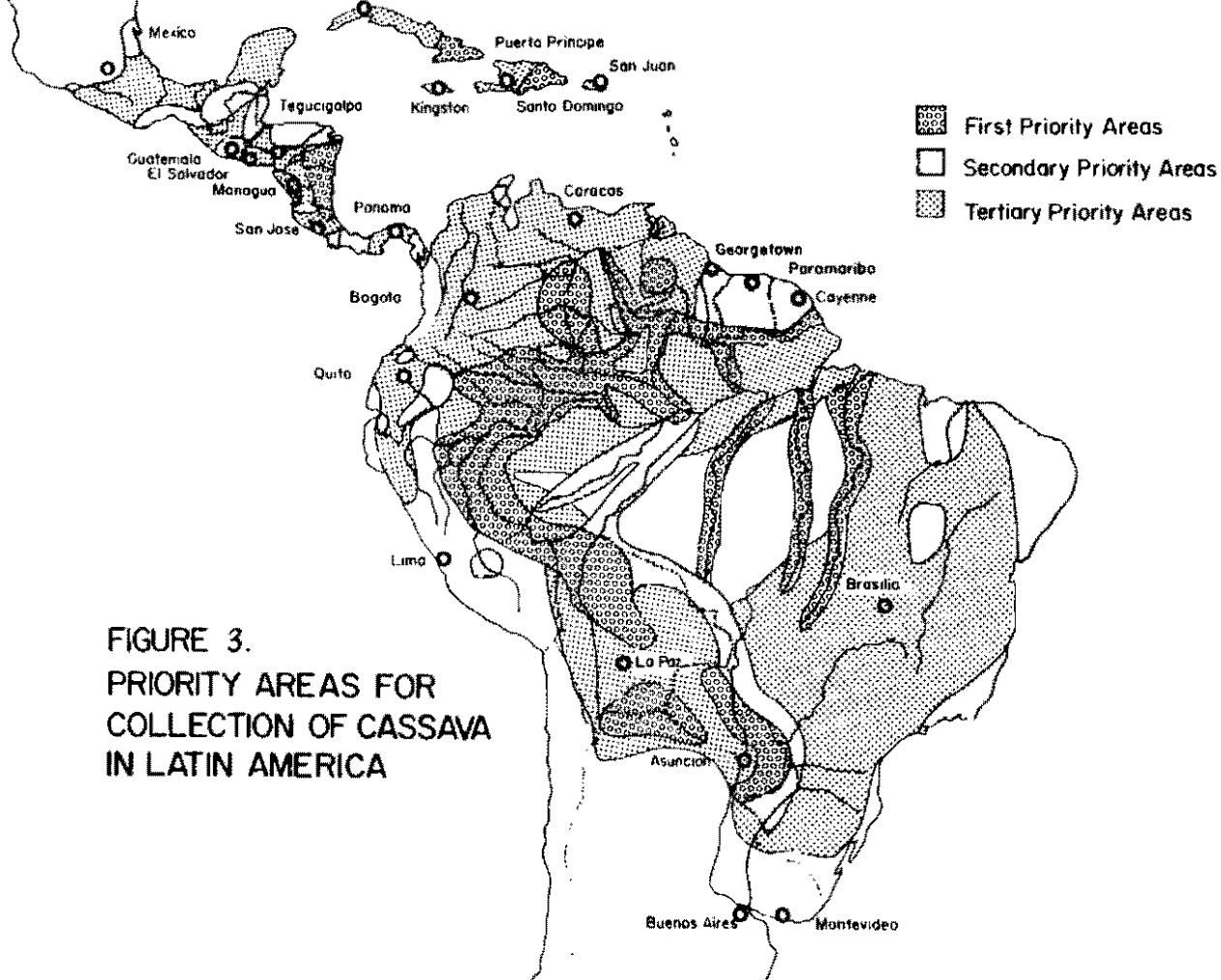
FIGURE 3.
PRIORITY AREAS FOR
COLLECTION OF CASSAVA
IN LATIN AMERICA

First Priority Areas
Secondary Priority Areas
Tertiary Priority Areas
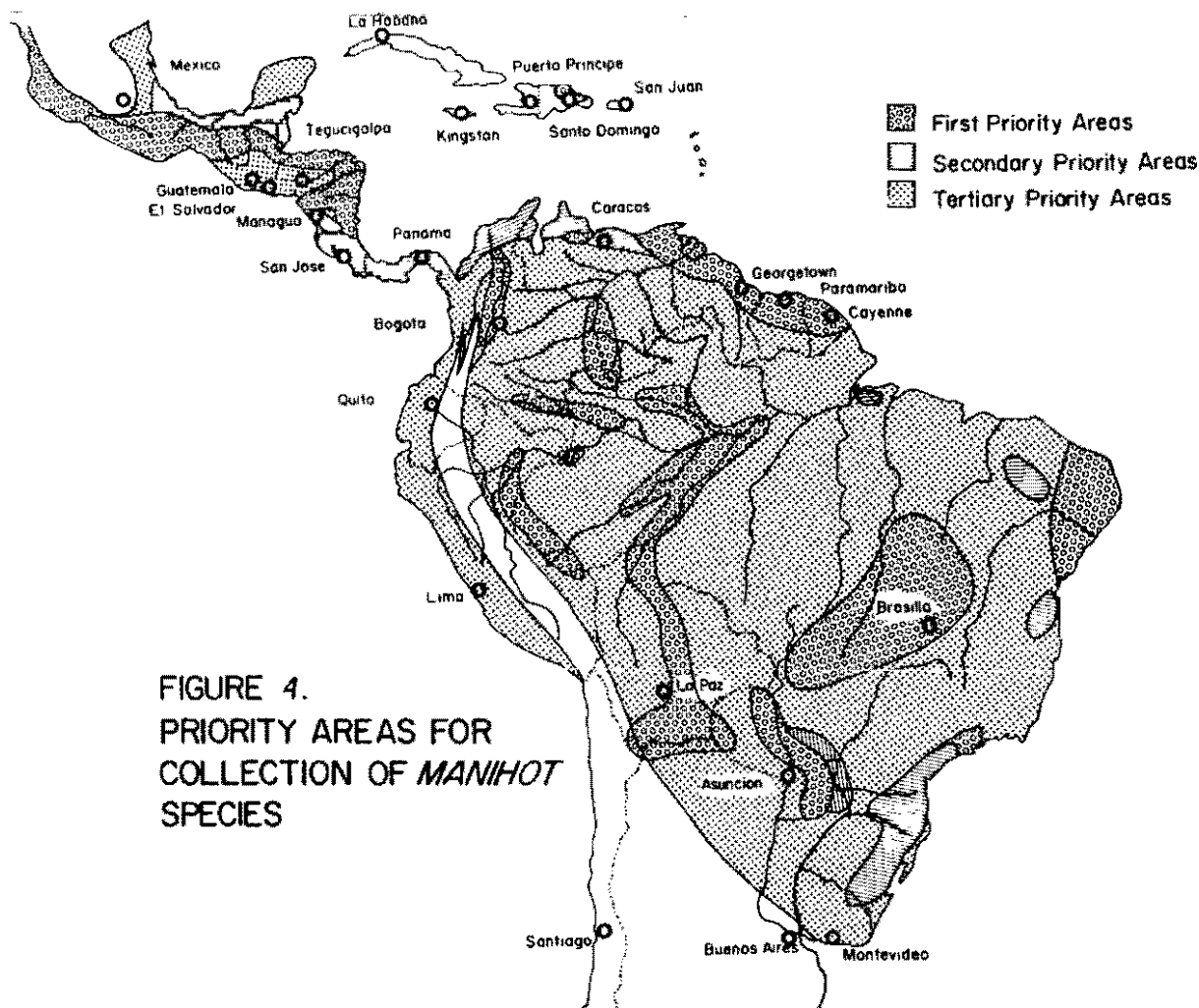
FIGURE 4.
PRIORITY AREAS FOR
COLLECTION OF *MANIHOT*
SPECIES

First Priority Areas
Secondary Priority Areas
Tertiary Priority Areas

riability, but is necessary to define existing variability, prevent genetic erosion of locally selected clones, and put at the disposition of breeders a broader genetic base for breeding. These priorities are based on best available estimates of areas of genetic diversity, previous exploration, and potential for genetic erosion (Patino and Hershey, 1981; Gulick *et al*, 1983). The IBPGR, CIAT and various national programs have been collaborating in recent years to collect cassava and wild species on the basis of these priorities.


CONSERVATION


At least 28 countries are known to have local, regional or international collections. The largest of these are at CIAT, Colombia (3680 accessions), EMBRAPA, Brazil (1960 accessions), IITA, Nigeria (1286 accessions), CTCRI, India (1279 accessions) and SRIFC, Indonesia (700 accessions)(Gulick *et al*, 1973)(Table 1). INIA in Mexico, and CENARGEN and the Universidade de Brasilia in Brazil have the largest available wild *Manihot* collections. Conservation of the wild species is difficult because many are not easily propagated either sexually or vegetatively. Recent work on *in vitro* culture shows promise for some of the species (CIAT, 1984).

Conservation of vegetative propagated crops has always been laborious and costly relative to seed conservation. Nevertheless it is often useful to maintain the specific gene combinations which have resulted from decades or even centuries of selection by farmers. Since cassava is highly heterozygous, the only means of conserving these specific gene combinations is through vegetative propagation. Alternatively, if the interest is conservation of genes rather than genotypes, germplasm could be maintained as true seed. Germplasm maintained in seed form would be useful principally as a source of genes in a breeding program and not directly as a source of varieties.

Cassava collections have traditionally been maintained in field plots. Stem pieces are used as the propagules just as in commercial prodution. Theorically, such a germplasm collection could be maintained for many years without regeneration, however, in practice, maintenance problems often increase after a year or two, making necessary replanting at more frequent intervals. Common problems include lodging from excessive growth and build-up of pests and diseases. A major advantage of field maintenance of collections is that they provide continuous availability of planting material for evaluations.

Recently, techniques have been developed for *in vitro* maintenance of cassava. The basic procedure is to cut sterile meristem tips, place them in nutrient media in test tubes, and maintain the cultures under controlled light and temperature condi-

TABLE 1.  MAJOR CASSAVA COLLECTIONS OF THE WORLD

| Collection | Details of samples | Geographical representation | Maintenance |
|---|---|---|---|
| CNPMF/EMBRAPA Cruz das Almas, Brazil | 750 cultivars; 12 species of *Manihot* | Brazil and Colombia | Plants |
| Departamento de Agronomia Univ. de Brasilia, Brazil | 21 species of wild *Manihot* | Brazil | Seeds |
| CIAT, Cali, Colombia | 3860 cultivars, 7 wild species | Throughout Latin America and Caribbean | Plants, *in vitro*, some seed |
| CTCRI, Trivandrum, India | 1279 cultivars | Mostly India, also S.E. Asia, S.America, Africa | Plants |
| SRIFC, Subang W. Java, Indonesia | 700 cultivars | Mostly Indonesia | Plants |
| IITA, Ibadan Nigeria | 1286 cultivars | East and W. Africa, Venezuela, Colombia, Brazil | Seeds and *in vitro* |
| National Cassava Center, Umvahia, Nigeria | 1060 cultivars | Mostly Nigeria | Plants and seeds |

Sources: IBPGR, CIAT

tions.   Under minimum growth conditions cultures can be maintain-
ed 18-24 months before renewal (Roca, 1983).   Facilities exist at
CIAT with potential capacity to hold 6000 accessions *in vitro*,
under the following conditions: 20°C(day), 15°C(night) temperatu-
res; 12 hr. photoperiod, and 500-1000 lux illumination.   Renewal
can be done by planting stem pieces or meristem tips from the *in
vitro* plantlet into new sterile media, without the need for a
field propagation phase.

Advantageous of *in vitro* conservation are the low space re-
quirements, low upkeep costs, and minimal possibility of loss of
materials through diseases, pest, climate, or soil factors.   Dis-
advantages are the need for relatively sophisticated facilities
for culturing sterile plantlets, and maintaining reliable mainte-
nance conditions.

A promising future possibility for vegetative conservation
is liquid nitrogen storage of meristem tips.   Procedures are
still at the experimental level, but successful regeneration of
cryopreserved clones has been recently accomplished (Kartha *et
al*, 1982).   The major problem has been the low rate of recovera-
bility, which should be possible to improve through further work
with cryoprotectants, and freezing and recovery techniques.   Ge-
netic stability could also be a concern, but preliminary tests
have shown no noticeable changes in plant characters after cryo-
preservation.   The major advantage is the virtual freedom from
maintenance problems during storage.   Conservation could theore-
tically be done indefinitely with no need for renewal.

Seed conservation in cassava has received limited attention.
Recent research however has shown that cassava seeds are probably
orthodox in behaviour and therefore can be stored under conven-
tional conditions of low humidity and low temperature.   IITA has
reported storing seeds at 5°C and 60% relative humidity for up
to seven years with no loss in germination ability (IITA, 1979).
CIAT has maintained a small collection of open pollinated seed
obtained from the field collection for five years under similar
conditions.   Preliminary observations suggest that cassava seed
can also be preserved in liquid nitrogen, if frozen slowly and
thawed in warm water (Mumford and Grout, 1978).

Apart from the mechanics of seed storage, further studies
are needed to define appropriate methodologies for seed produc-
tion.   First, basic populations need to be delineated, in terms
of origin, morphological or agronomic characteristics, biochemic-
al features, or other criteria.   In order to preserve the inte-
grity of these populations, the following requirements must be
met: (1) avoid contamination by foreign pollen through isolation;
(2) avoid random drift by using an adequately large number of ba-
sic plants; (3) achieve random mating; (4) avoid shifts through
natural selection, particularly for high seed production; and
(5) ensure highest possible yields of good quality seed to mini-
mize subsequent regenerations.

These criteria are not easily met in cassava, and much basic work needs to be done before even considering a seed germplasm storage system. The long term advantages, however, warrant some work in this area.


EVALUATION


A germplasm collection is useful as a resource to breeders only insofar as accessions are described in terms of characteristics of interest. Agronomic evaluation, and selection are normally closely linked activities, and therefore it is essential either that they are carried out within the same interdisciplinary team, or that the persons carrying-out the two activities have close communication. Most of the criteria developed for germplasm evaluation also apply to evaluation of breeding lines, as there is no sharp distinction genetically between the two.

The IBPGR, based on working group recommendations, has developed a descriptor list for cassava (Gulick *et al*, 1983). Descriptors are divided into two categories: (1) characterization, which consists of recording those characters which are highly heritable, can easily be seen by the eye and are expressed in all environments, and (2) preliminary evaluation, which consists of recording a limited number of additional traits of lower heritability throught desirable by a consensus of users of the crop.

Although these descriptors cannot be considered definitive, the generalized use of this scheme will produce a rapid, reliable and efficient means for information storage, retrieval, and communication, and subsequently augment the utilization of germplasm. Characterization is important basically as a tool for varietal description and for identification of duplicates in a collection.

Isozyme systems have now been identified for use in cassava characterization (Table 2). Electrophorethic techniques have been validated with 12 isozymes, two buffer systems and two tissues (young nodes and root tips)(CIAT, 1985b). These techniques will provide a powerful tool for duplicate identification, for monitoring genotypic stability of clones stored *in vitro* or in other non-conventional forms, and for varietal fingerprinting.

For purposes of discusssion, preliminary evaluation can be divided into five aspects:(1) general adaptation; (2) resistance; (3) plant architecture; (4) yield; (5) root quality ; and (6) other locally important traits.

A first step is to define the objectives of evaluation. This should seem obvious, but is in practice often inadequately planned. Collections are often maintained and evaluated by germplasm

76

TABLE 2. ISOZYMES AND BUFFER SYSTEMS FOR EVALUATION OF
CASSAVA STORED *in vitro*.

| Isozymes | Buffer system | |
|---|---|---|
| | STD | PC |
| Acid phosphatase | + | |
| Alcohol dehydrogenase | + | |
| Glutamate-oxaloacetate-transaminase | + | |
| Glutamato dehydrogenase | | + |
| Isocitric dehydrogenase | | + |
| Malate dehydrogenase | | + |
| Malic enzyme | + | |
| Peroxidase | + | |
| Phosphogluco-isomerase | + | |
| Phosphogluco-mutase | | + |
| 6-phosphogluconate dehydrogenase | | + |
| Shikimic dehydrobenase | | + |

Source: CIAT, Cassava Tissue Culture Annual Report, 1984.

curators who may have little appreciation of the needs of plant breeders. The need for good communication between the two specializations is apparent. A general objective is usually to identify clones which can be used directly as recommended varieties, or as parents in a breeding program. On this generalized objective then hinge many other crucial decisions. If the objective of evaluation is to find material for a breeding program further criteria depend on the objectives of the breeding program, *vis a vis*, target production areas and their physical and biological characteristics, management practices to be employed, and market and consumption characteristics.

If large numbers of germplasm accessions are being evaluated, a multiple stage evaluation may be advisable, where in the first cycle, small plots (such a single, unreplicated rows) are used to discard obviously inferior material, and in later stages selected clones are more thoroughly evaluated.

General Adaptation

General adaptation includes the ability of the plant to germinate and grow reasonably under a given set of environmental conditions. This is basically a physiological adaptation to temperature, light and humidity conditions, and cropping system. Because genotype-environment interaction is a universal phenomenon in crop plants, it is critical that agronomic evaluation be done under conditions reasonably similar to the target production area in terms of climate and soils. Management practices should be similar to those recommended for commercial production, in terms of land preparation, fertilization, stake treatment, planting system, and weed control, as there can be genotype-environment interaction for any of these components.

On a worldwide basis, cassava is generally cultivated on poorer soils and more marginal areas, so for most programs it is most appropriate to evaluate germplasm under the types of stress which are encountered in commercial production fields, rather than to seek maximum productivity under optimum conditions. If the target production area is edaphoclimatically diverse, various evaluation sites should be used. Experiment stations are usually located on the best land, in which case they may not be appropriate sites for agronomic evaluation of cassava germplasm.

Criteria for evaluation of adaptation are not always easy to define, as complex physiological systems may be involved. A methodology which evaluates general growth and vigor during the growing season, and yield at harvest, is probably and adequate system. Often it is not possible to separate an evaluation for general adaptation as described above from resistance to physical factors or from yield potential.

## Resistance

Because pests* occur and develop in somewhat unpredictable ways, their evaluation is generally more complicated than evaluation for adaptation to physical factors. Pest evaluation should concentrate first on those problems of known importance in the target production area (key pests), and secondly, on those of potential importance based on edaphoclimatic conditions and geographic proximity of the pest or pathogen.

Many pest problems can be evaluated at the field level. Severity and/or uniformity of distribution within the evaluation field may have to be adjusted to achieve reliable evaluations (for example, by susceptible spreader rows or artificial innoculation). The long growing cycle of cassava facilities multiple pest evaluations; in many areas disease evaluations·can be done during the rainy season and mite or insect evaluations during the dry season.

A common problem encountered in pest evaluations is the inability to adequately differentiate individual pests when a complex of problems is present. Various alternatives are possible. If selective fungicides or insecticides are used during given periods, it may be possible to more effectively evaluate individual problems. For some pests, greenhouse or screenhouse evaluation can be used. However, this methodology must be chosen with great care to be certain that the results are highly correlated with field performance. Many reports of greenhouse evaluation techniques are available, but few have proven to be more reliable than field evaluations.

As a rule, in Africa and Asia, number of pest problems are limited (though sometimes severe), so evaluations may be relatively uncomplicated. In Latin America, where a wide range of pest problems evolved simultaneously with the cassava crop, defining an appropriate evaluation procedure can be more complicated. Nevertheless, on a regional basis, a small group of the most serious problems can usually be defined and given priority for evaluation.

## Plant Architecture

Plant architecture in cassava is important for several reasons, including adaptation to specific cultural practices, production of vegetative planting material, and influence on carbohydrate distribution contributing to top growth versus root

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\*   The term "pests" will be used throughout to refer to either arthropod pests or pathogens.

yield. Much has been written about the ideal plant type for maximum yield (Cock *et al*, 1979) and effects of different stresses on yields in plants and differing architecture (CIAT, 1985a; Cock, 1978; Conner and Cock, 1981). The need for physiological redundancy as an insurance against loss to insects, diseases or other leaf area reducing stresses, and the need to produce adequate numbers of high quality stem pieces for reproduction must be balanced against efficient partitioning of carbohydrates to the roots under optimum conditions.

Plant architecture is also an important consideration for specific cropping systems. Nevertheless, a generalization seems to be that upright, later branching types are preferable either for intercropping or monoculture systems (Leihner, 1983). Very vigorous plant types have a competitive advantage against weeds, but are generally of low yield potential due to low harvest index.

Yield Potential

General adaptation and pest resistance must be combined with good yield potential. Yield potential can be defined in a number of ways. Physiologists tend to think of yield potential as the yield obtained under ideal conditions. However, this definition may have limited usefulness in cassava, where ideal conditions are rarely achieved or even approached under commercial production, for reasons described above. A more practical definition would be to consider yield potential as the yield obtained under representative edaphoclimatic conditions and under improved management conditions which are economically within the reach of growers in the target area, but where pests and diseases are controlled. This definition allows a practical estimate of potential yields on a commercial scale, where pest and disease resistance is to be incorporated, and good, but not luxurious, agronomy is practiced.

Root Quality

Requisites for cassava root quality vary considerably depending upon end use of the product and regional preferences. Three broad categories can be defined, which largely differentiate quality requirements: fresh human consumption, processed for human consumption, and industrial use. A detailed analysis of different quality requirements for these markets is beyond the scope of this paper, but a few generalizations can be made in terms of evaluation procedures.

For the large majority of end uses, high root starch content is desirable. Several rapid methods have been described based on the high correlation between starch content and dry matter content For fresh consumption, there are as yet not well-defined methodo-

logies for quality evaluation apart from actual cooking tests. A preliminary elimination can however be based on dry matter(DM) content and HCN (those with either low DM or high HCN being unacceptable). Rapid qualitative methods of HCN analysis are adequate for a preliminary evaluation, while more sophisticated quantitative analysis can be used at the final stages.

For processed cassava for human consumption, quality requirements are less stringent. For some such uses, high HCN is unimportant, or even preferred. For indutrial purpose, quality requirements are generally even less stringent, but requirements do exist, for example, relative to dry matter, fiber or HCN content, ease of peeling, root color, parenchyma color and others.

A general suggestion should be that before designing a germplasm evaluation program, the quality requirements of the actual and potential markets in the region be thoroughly studied to determine which quality parameters need to be evaluated, and the range of acceptability for those parameters.

## Other Traits of Regional or Local Importance

In addition to the above generalized evaluation criteria, specific local and regional needs may define other important criteria. Some known examples of these types of traits are root surface color (light or dark), root parenchyma color (white or yellow), plant type suitable to particular crop associations, characters associated with consumption of leaves as a vegetable, and many others. Only through a complete knowledge of local cultural practices and marketing and consumption patterns can the best evaluation strategy be defined.

## Characteristics of native cassava germplasm

CIAT has done extensive evaluations of its germplasm collection under diverse soil, climatic and pest conditions (CIAT, 1980, 1981, 1982, 1984, 1985a; Hershey, 1983a, 1983b; Kawano *et al*, 1978). Some generalized conclusions can be drawn from these evaluations relevant to setting breeding objectives and defining evaluation criteria. These conclusions apply only in a general, overall sense to cassava germplasm, so probably many exceptions could be cited.

1. Within cultivated cassava, there exists a wide range of diversity for nearly all traits so far studied, including morphological, agronomic and resistance. For virtually all pests studied, the resistance ranges from highly resistant to highly susceptible. Yield and quality traits and adaptation to soil conditions cover wide ranges. Though limited to growth in the tropics and subtropics, considerable variation exists for sensitivity to temperature and photoperiod. Variation for physiological

processes is only recently being investigated, but indications are that high variability exists for photosynthetic rate, stomatal sensitivity to air humidity, and others (CIAT, 1984; 1985 a).

2. Although cassava as a species is adapted over a wide range of conditions, the range of adaptation of a given native variety is usually very limited.

3. Most traditional varieties appear to be well adapted to traditional cultural practices but do not respond well to improvement in those practices. Local varieties tested in trials in Colombia have consistently responded less to improved cultural practices than do selected hybrids (Kawano and Jennings, 1980).

4. Most traditional varieties have evolved with multiple resistance to the pests in a given region (Fig.2). However, these resistance levels are generally low, since pest control in traditional cultivation systems is accomplished not only by varietal resistance, but also by isolation in space, through intercropping, burning and other cultural practices.

5. Yield potential of the majority of existing accessions is low and is manifested particularly as a low harvest index. Cassava evolved under cultural systems where competitive ability was highly important both for survival and for reproduction, since stem weight is generally negatively correlated with productivity (Kawano and Jennings, 1980).

6. There exist a significant number of accessions having favorable characteristics that have not yet been exploited in breeding programs.

7. Genetic recombination will play the major role in the future for producing acceptable genotypes under conditions of improved cultural practices.


DOCUMENTATION


Few cassava germplasm collections are well documented. Although certain minimal evaluations have been made in many collections, these data are generally poorly organized and difficult to interpret. Among the best documented collections are those of CATIE in Costa Rica (Engles, 1981), CENARGEN and CNPMF in Brazil (Silva, 1981), and CIAT. All have computerized evaluations which are either published or available on request. The extensive nature of the data on large germplasm collections limits the possibility for their wide distribution, but persons with specific interests can request computer searches for the relevant data.

UTILIZATION

The eventual utility of germplasm collections is generally
in breeding programs.  Special importance will be given here to
the principles and procedures for moving from basic germplasm
to improved varieties.  This is of course a broad subject area
involving the whole gamut of plant breeding philosophy and me-
thodology.  Here we will discuss only some basic concepts.

In crops with a long history of genetic improvement for
modern agricultural conditions, there is generally a large ge-
netic gap between bred varieties and land races.  This is the
case for the world's major grain crops--wheat, rice and maize.
In these crops, apart from transferring single gene or oligoge-
nically controlled traits, the utilization of basic germplasm
is a complex process.  Along with transferring the desired trait
or traits, a whole range of undesirable traits is carried along,
and many cycles of recombination may be required to break link-
ages and return to the desired background genotype.

In cassava this is less of a dilema.  Modern breeding meth-
ods have a short history.  Though significant gains have been
made in breeding, the genetic differences between good landrace
varieties and improved varieties are not extreme.  Basic germ-
plasm can therefore often be used as a source of any number of
traits without major complications normally associated with exo-
tic germplasm.  Nevertheless, the efficient utilization of basic
germplasm in cassava breeding requires good planning.

The generalized characteristics of cassava germplasm given
in the previous section help define some of the basic breeding
objectives.  The methodology to meet these objectives is not
necessarily self-evident.  Given that most cassava will continue
to be grown under suboptimal conditions, with an array of biolo-
gical and physical stresses acting throughout the long growing
cycle, it becomes clear that no single, simply inherited charac-
ters are likely to dramatically increase productivity, and espe-
cially in the center of origin where biological constraints are
many.  Further, virtually all important agronomic traits appear
to be multigenically controlled.  With this situation, it beco-
mes critical to consider a plant genotype as a complex and in-
tegrated gene system, where it is virtually impossible to modi-
fy one character to the exclusion of others.

The most effective utilization of basic germplasm in breed-
ing can often be made not by looking exclusively for genotypes
showing highest expression of a single trait, but rather those
showing moderate to high expression in a nearly acceptable gene-
tic background.  Through population improvement methods, several
characters can then be improved over time.

The use of wild species in cassava breeding has been limit-
ed, with the most notable exception being the transfer of resis-

83

tance to cassava mosaic disease from *Manihot glaziovii* (Hahn *et al*, 1980). There seem to be few if any compatibility barriers among the *Manihot* species, however, so potentially, greater use of wild species could be made without many of the incompatibility problems that plague other crops. As a general rule, use of wild relatives of crops for transferring individual traits should be a last resort, when insufficient variability is found in the cultivated species.

Some breeders have the concept that introduced germplasm must necessarily be better than local germplasm. But before introduction, a careful analysis of defects of available germplasm, and ability of introduced germplasm to correct or improve those characters, is necessary. Until locally available germplasm is well evaluated, introduced germplasm can probably not be efficiently utilized.

International centers and national programs can play complementary roles in promoting efficient germplasm utilization. National programs have the obligation to know first of all what germplasm is locally available, its characteristics, and which of these need to be improved. International centers have a similar responsibility to have their germplasm resources well evaluated and catalogued, but, in addition, available for international exchange. Major germplasm banks, either national or international, should have the ability to identify genotypes which can best complement locally available germplasm.

There is no sharp distinction between the management of basic germplasm and of breeding lines in terms of their utilization in practical breeding programs. In some cases the germplasm needs of a breeding program may best be met with germplasm accessions, and in other cases with improved varieties. A distinction can be made, however, in the manner in which germplasm is received--either as vegetative material or as true seed. By receiving vegetative material, a breeding program receives a clone of known characteristics, and probably can identify *a priori* a methodology for making use of the clone--either testing for possible direct use as a variety or incorporation into hybridization blocks. Material received as true seed is highly variable and is often most appropriately first selected before use as parental materials, or alternatively, used directly for selection of improved varieties.

The introduction of germplasm for one region to another, and especially across national boundaries, always entails some risk of pest dissemination. Virus indexing techniques, seed treatment methods, and *in vitro* techniques are all contributing immensely to improve the security of germplasm exchange. Nevertheless, quarantine regulations are highly variable across countries and may be either too stringent or not stringent enough with regard to cassava (Roca *et al*, 1982). Basic responsibility for assuring phytosanitary status of materials lies ultima-

tely with both the source and the recipient.

SUMMARY

One of the most promising possibilities for improving pro-
ductivity of cassava is through genetic improvement of yield po-
tential and resistance or tolerance to physical and biological
yield constraints. The immense genetic diversity of cassava has
not yet been adequately collected, but is collected to a suffi-
cient degree to provide variability to breeders for nearly all
traits of agronomic interest. Collection and utilization of
wild species, however, has been limited, with a few notable ex-
ceptions such as transfer of resistance to cassava mosaic dis-
ease.

A prerequisite to successful utilization of germplasm is
to have the available germplasm base fully evaluated under con-
ditions representative of the target production area. Introduc-
ed germplasm can have a large impact on genetic progress, espe-
cially if the locally available germplasm base is limited.

TABLE 3.   DESCRIPTORS RECOMMENDED BY IBPGR FOR CHARACTERIZA-
           TION OF CASSAVA

| Leaves and petioles | Stem | Roots |
|---|---|---|
| Color of unexpanded apical leaves | Stem color | Storage root Surface color |
| Color of first fully expanded leaf | Number of levels of branching | Storage root Pulp color |
| Shape of central lobe | Angle of branching | Root HCN content |
| Petiole length | Height of first apical branch | |
| Petiole color | Height to top of canopy | |
| Pubescence of young leaves | | |

Source: IBPGR

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# HYBRIDIZATION AND BREEDING METHODOLOGIES APPROPRIATE

# TO CASSAVA[1]

Alvaro Bueno*

## ABSTRACT

Cassava (*Manihot esculenta* Crantz) is a crop propagated vegetatively by means of stem cuttings, but it also has the capability of sexual reproduction. Hybridization is used mainly for creation of genetic variability. A review is made of cassava's flower biology and pollination habit. Hand crossing and pollination procedures are discussed. Methods of cassava breeding, such as introduction of cultivars and hybrid progenies, intraspecific and interspecific hybridization, population improvement and non-conventional methods are presented. A half-sib recurrent selection scheme proposed by the CNPMF, Brazil, is explained.

## FLOWERING BEHAVIOR AND POLLINATION HABIT

CASSAVA (*Manihot esculenta* Crantz) is monoecious species with few large basal pistillate and numerous smaller apical staminate flowers botne in the same inflorescence (Chandraratna and Nanayakkara, 1948). Flowering is always associates with branching points; therefore an early branching genotype may start flowering as early as three months after planting and a non-branching type does not flower (Hahn *et al*, 1973; Conceicao, 1979).

Pistillate flowers have five petals and an ovary with three loci, each of which produces one seed. Staminate flowers have ten stamens arranged in two rings of five and do not initiate opening until after the last female flower of the inflorescence has bloomed (Graner, 1942a).

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Anthers start dehiscence before the staminate flower opens, but complete it only by time of opening. One male flower produces about 1600 pollen grains of which only 50% are viable (Graner, 1942a). Pollen grains stored over calcium chloride were maintained viable for up to 6 days (Chandraratna & Nanayakkara, 1948).

Male sterility has been reported in cassava and several mechanisms for this have been described, including: early abscission of staminate buds, no pollen formation, non-dehiscent anthers and chromosomal pairing aberrations (Byrne, 1984).

The stygma is sticky and receptive at the time of blooming, becoming non-viable within 24 hours. It secrets a sugary solution which is visible to the naked eye on the day the female flower opens. Changes in the size and format of the flower, and the nectar secreted by the stigma, aid in identification of flowers which will open the same day (Fukuda, 1980; Hershey and Amaya, 1980).

There seems to be a concentration of blooming around midday in most cassava growing environments (Chandraratna and Nanayakkara, 1948; Conceicao, 1979; Hahn *et al*, 1979; Hershey and Amaya, 1980) flowers stay open only for a short period of time during the day (Fukuda, 1980).

Most genotypes flower preferentially during short days (Hershey and Amaya, 1980). In the northern hemisphere flowering occurs from July to January with a peak in October to December. In the southern hemisphere flowering occurs from January to July with a peak in April to June (Hahn *et al*, 1979). However, flowering time depends also on temperature and humidity. On cold and rainy days flowering is less intense and delayed (Fukuda, 1980). In soil moisture deficit environments flowering may be erratic (Byrne, 1984).

Prolific production of readily disseminated pollen grains suggests that wind may be an important pollinating agent, though this has not been confirmed experimentally. Profuse secretion of nectar attracts several insects, specially bees, which are also pollen disseminators (Chandraratna and Nanayakkara, 1948).

The flower biology and pollination habit of cassava make it a predominantly alogamous species, but considerable selfing may occur, because the protogynous flowering mechanism prevents selfing in the same inflorescense, but not in the same plant, especially in profusely flowering genotypes (Kawano *et al*, 1978).

## Hybridization Methods

Due to the alogamous condition of the species, most culti-
vars are highly heterozygous. However a field of a cultivar
is composed of homogeneous genotypes, since the normal type of
propagation is vegetative by means of stem cuttings. Therefore,
hybridization of selected parents is necessary for creation of
source populations with high genetic variability.

## Hand Pollination

With large separate male and female flowers which do not
open at the same time, it is very easy to hand pollinate cassa-
va flowers. Although the procedure is simple, the cost of pro-
ducing large quantities of hybrid seeds is considered high (Gra-
ner, 1942a). One successful pollination yields a maximum of
three seeds, but this is seldom obtained and in most situations
one seed per pollination flower is a good average. Byrne (1984)
estimated that one person can produce from 50-300 seeds per day,
which compares unfavorably with other crops where just one pol-
lination can produce that many or more seeds.

The pollination procedure begins in the morning, when ready
to-open staminate flowers, of chosen male parents, are collect-
ed and kept in small glass or plastic vials properly identified.
Simultaneously, female flowers which are due to open that day
are protected with a fine cloth or white paper bag, before the
flowers open, to prevent contamination from foreign pollen (Fu-
kuda, 1980; Hershey and Amaya, 1980).

The actual cross is accomplished after·midday when female
flowers are open inside the bag. Pollen is transferred by us-
ing the male flower as an applicator or a velvet-tipped pollen
applicator. In either case pollen grains are deposited on the
stigma by gently rubbing the applicator on it. When the velvet
tipped applicator is used, several female flowers can be polli-
nated without recharging it. If the applicator is to be used
for other pollen parents, it should be dipped in alcohol before
reuse. One staminate flower has enough pollen for 3-4 stigmas.
Unopen female flowers, which have not been pollinated, should
be eliminated from the inflorescence to avoid future confusions.
Male flowers may be eliminated but it is not necessary, since
they will not interfere with the pollinations (Hahn *et al*, 1979;
Conceicao, 1979; Fukuda, 1980; Hershey and Amaya, 1980).

After the cross is made it should be labeled with name of
parents, date and number of flowers pollinated. Flowers may be
immediately covered with fine cloth or white paper bags or they
may be immediately covered with fine cloth or white paper bags
or they may be left uncovered for a few days, and bagged when
the ovary starts swelling. Developing fruits should be kept

covered up to maturity to avoid insect injury and catch the
s_ed upon dehiscence.  Seed matures 2.5-3 months after polli-
nation (Chandraratna and Nanayakkara, 1948; Hahn *et al*, 1979;
Fukuda, 1980; Hershey and Amaya, 1980; Byrne, 1984).

     The rate of success of hand crossing seems to vary widely.
Fukuda (1980) reported that 80% of pollinated flowers set
fruits.  On the other hand, Conceicao (1979) and Albuquerque
(1961) stated that only 15-20% formed fruits.  In Nigeria most
cultivars set seed readily when hand crossed, but almost 100%
failure was observed when "Llanera" was polinated.  This same
cultivar set seed satisfactorily when ut was naturally pollinat-
ed by insects (Hahn *et al*, 1973).

     A number of insects are known to reduce cassava's ability
to produce viable seeds.  Larvae of *Teleocoma grassipes* Aldrich
bore staminate buds and decrease considerably the amount of
pollen formation.  After pollination, larvae of *Anastrepha* sp.
penetrate the developing fruit and damage the seed (Graner,
1942a).  In environments which favor high popullations of these
insects, cassava seed production is almost nil under natural
conditions.  In the period of 1978-79 seed production per pol-
linated flower at CIAT headquarters decreased from 0.7 to 0.28,
due to an increased population of fruit flies.  Biweekly appli-
cations of fenthion increased the efficiency to 0.82 seeds per
female flower (CIAT, 1981).


Open Pollination

     Observations made in CIAT's germplasm bank have shown that
yield potential of most accessions was low and very few genoty-
pes had the necessary levels of combined resistance to disease
and pest problems (CIAT, 1982).  This suggests that frecuency
of desirable alleles in most accessions is low.  Therefore, a
cassava hybridation program will require a very large number
of hybrid seeds from any particular cross combination for pro-
duction of superior recombinant types (Kawano, 1978).  Open
pollinared crossing fields are efficient mechanisms for econo-
mic production of large quantities of hybrid seeds.


Natural Open Pollination

     Normanha (1971) and Conceicao (1979) reported that the
first cassava breeding efforts in Brazil were initiated by ga-
thering open pollinated seeds in germplasm collections.  This
procedure has the inconvenience of allowing a considerable num-
b_r of undesirable pollen parents to participate in the crosses,
reducing the probability of obtaining a superior segregant. Ad-
ditionally, Kawano (1978) reported that uncontrolled open pol-
linated progenies of two cultivars included a large portion of

selfed lines and that most of these did not yield even half
that of the parent.

In environments where the population of fruit flies is
high, bagging of developing fruits is required.  Application
of insecticides is not recommended, since it will reduce the
population of pollinating insects.

## Controlled Open Pollination

Strategic location of plants within the field can increase
the rate of natural crosses and reduce the problems of selfing.

Hahn *et al*, (1979) suggested that crosses among selected
parents should be made in isolation.  Each crossing plot should
contain several parents, few plants per parent, and be replicat-
ed several times to maximize outcrossing.  Conceicao (1979)
stated that isolated crossing fields should have one pollen do-
nor row for every three female rows, which should be emasculat-
ed at regular intervals.

Instalation of several isolated crossing fields has been
recommended by Silva (1971).  The number of fileds should be
equal to the number of parents selected for crossing.  In each
field one different parent functions as pollen donor and all
others are emasculated regularly.

Another scheme was used by Acosta-Espinoza (1984) who cros-
sed nine progenitors.  Each crossing plot consisted of nine
plants and only the central plant, which was different genotype
in each plot, was used for seed collection.

Simple randomization of parents within the crossing plot
and systematic arrangements such as latin square design may be
used successfully.

Whatever the arrangement, bagging of developing fruits is
required for protection against fruit flies and collection of
seeds after dehiscence.  In sites where fruit flies are not a
limiting problem, fruits in isolation plots may be left unpro-
tected and collected when the seed coat begins to shrivel, in
cloth bags left hung on the plants (Hahn *et al*, 1979).

## Breeding Methods

Cassava is a crop subjected to stresses of various nature.
It is grown with zero or low fertilizer, without irrigation or
chemical control of diseases and pests, and usually in marginal
lands.  Throughout its long growing cycle it is exposed to a
wide range of physical and biological constraints.  Considering
this situation, the main objective of CIAT's breeding program

is to exploit the ability of the crop to produce reasonable and stable yields under marginal conditions with low inputs (Hershey, 1983).

The major biological constraints for cassava production in Africa are diseases and pests. Major diseases are cassava mosaic (CMD), bacterial blight (CBB) and anthracnose (CAD). Important pests are cassava mealybug (CMB) and cassava green s-ider mite (CGM). Because of limitations in the use of chemical products to control pests and diseases, development of resistant genotypes becomes the most appropriate and realistic approach for effective control (Hahn *et al*, 1980).

Although individual breeding programs have their own specific objectives, most programs aim at developing genotypes which combine the largest number of desirable traits associated with high root yield, disease and pest resistance, good root quality and stability of production across environments.

Since cassava can be vegetatively propagated, superior genotypes identified in any phase of a breeding program may be maintained indefinitely. Vegetative propagation combined with sexual reproduction allows for reliable estimates of environmental and genotypic variance. Given that inbreeding is deleterious (Kawano, 1978) and heterozygosity is essential for maintenance of vigour, any breeding method should maintain heterozygosity and take into account both additive and non-additive genetic variance (Byrne, 1984).

## Introduction of Cultivars

Introduction of a number of foreign cultivars into a region and selection of the most adapted is a very simple and low-cost approach to crop improvement. Its classigication as a breeding method may be contested, but it is indeed widely used. The method is generally practiced by programs which are initiating their activities.

Since the introductions are usually in the form of stem cuttings, only a limited amount of genetic variation can be brough in, and there is a risk of introducing diseases and pests. However, no special requirement is needed for manipulation of the planting material. Cultivars may be introduced in the form of meristem cultures, which will reduce risk of introduction of diseases and pests, but requires some facilities for manipulation.

Each introduced genotype is initially planted in a single row of 5-10 plants without replication. All evaluations at this stage are preliminary and selection is usually very mild. In general, only genotypes which are extremely susceptible to

96

diseases and pests and clearly show no adaptation to the eco-
system are discarded. It is recommended to included a row of
a local cultivar every 5-10 rows as a check.

In the second and subsequent years each selected cultivar
is planted in larger plots, with replications in one or more
locations, depending on the amount of planting material avail-
able. Selection intensity increases and selection criteria
become more rigid. If one or more introductions prove to be
superior to the common cultivar of an ecosystem, they may be
recommended for commercial use. Although the method is low-
cost, the probability of an introduced genotype being superior
to locally adapted cultivars is low, because most introductions
have been selected in ecosystems with different biological and
physical constraints, and will probably not have all characte-
ristics necessary for good performance in the new environment.

## Introduction of hybrid progenies

Introduction of seeds of selected crosses has been the
advantage of introducing much wider genetic variability with
reduced risks of bringing in diseases or pests. However, this
approach requires some facilities for seed germination and
seedling transplant, which may impose limitations for some pro-
grams.

The initial step is the germination of seeds directly in
the field or in seed beds with subsequent transplant of seed-
lings. In either case irrigation may be necessary, because
seedlings are very sensitive to water stress.

Since the number of seedlings is usually large, selection
must be rather intense. The efficiency of selection depends
primarily on the traits being selected. It is more effective
for traits with high heritability, such as disease and pest
resistance and less effective for low heritability traits, such
as root yield. Selection is practiced among progenies and
within each progeny.

Selected seedlings are cloned and planted in single rows
of 5-10 plants. Best clones are selected and subsequently eva-
luated in larger plots with replications and in various loca-
tions. If a clone is judged superior to local checks it may
be released as a new cultivar.

This procedure may be classified as low cost, because it
does not spend resources for parental evaluation and selection,
and more efficient than introduction of cultivars, because it
selects from a much wider genetic base. However, its effec-
tiveness is hampered by the fact that parents have not been
selected within the target ecosystem and their progenies may
lack important alleles for good agronomic performance in the

new environment.

Both CIAT and IITA place strong emphasis on sending hybrid progenies, with appropriate adaptation and resistance, to national programs.

## Intraspecific hybridization

Hybridization in cassava is used mainly for the creation of genetic variability. Most cultivars are heterozygous at the majority of their loci; therefore segregation will occur at the first hybrid generation. Thus, each hybrid seed is potentially a new cultivar.

Probably the most common procedure for cassava breeding is selection of superior parents within the species *Manihot esculenta* and evaluation of hybrid progenies of selected crosses (Hahn *et al*, 1973).

The success of this method depends primarily on the choice of adequate parents and on the selection mechanisms used (Kawano, 1980). Selection of parents is normally practiced by phenotypic evaluation of cultivars and should be complemented by evaluation of combining ability of best parents (Hahn *et al*, 1979).

Some breeding programs give priority to field evaluation for selection of superior parents. The choice of adequate selection sites become very important and a good site should include as many physical and biological constraints as possible, so the final selections may have a chance of being widely adapted (Hahn *et al*, 1980 and Lozano, 1983).

In each selection site evaluation aim toward selection of genotypes with durable integrated resistance to most constraints. Best genotypes are evaluated for several growing cycles and those which prove superior enter the crossing blocks (Hershey, 1983).

After several years of evaluation of CIAT's cassava germplasm it was observed that yield potential of most accessions was low, frecuency of accessions with combined resistance to all diseases and insects of a given region was still lower and genotypes had a limited range of adaptation. It was concluded that only a few cultivars could be used directly as parents for production of acceptable hybrids. More recently, new superior hybrids have entered the hybridization process and the parental base is continuously being upgraded (Hershey, 1983).

In Brazil, the evaluation and selection of superior parents is carried out by introducing a large number of cultivars in almost all states, for local evaluation and selection of the

adapted. These activities are coordinated by CNPMF and execut-
ed by state research units.

In Nigeria potential parents are selected from collections
of local and introduced cultivars which are evaluated for dis-
ease and pest resistance, root yield and quality, consumer ac-
ceptance and general adaptation to a range of environments
(Hahn *et al*, 1979).

Ideally, selection of hybrid progenies should be carried
out in as many sites as possible within a target region, but
breeders are often restricted to few sites. Therefore, the se-
lected site should be carefully chosen and include as many of
the relevant biological and physical constraints as possible.
Very often clones give variable results when grown in places
other than selection sites. This suggests that regional eva-
luation is necessary (Lozano *et al*, 1980).

Maximum adaptability to a given ecosystem should be achiev-
ed by initiating selection directly from the first hybrid gene-
ration within the target region, but in sites with moderate to
high stress conditions, seed germination is usually low, plant
development is slow and yield formation is delayed. This may
cause serious problems in selection efficiency (Hershey, 1983).

In order to assess the possibility of preliminary selection
at CIAT headquarters for clonal performance in Media Luna, Co-
lombia, hybrids seeds were planted in CIAT and Media Luna. At
harvest, five stakes from each plant from both sites were plant-
ed in single rows in Media Luna. Correlation for root yield
between seedlings grown in CIAT with stakes planted in Media
Luna was very low. On the other hand, correlation between
seedling and stakes grown in Media Luna was high and statisti-
cally significant, suggesting that *in situ* selection for root
yield was more effective (Hershey, 1983). This is in agreement
with results reported by Kawano (1980).

Considering these problems, the present selection scheme
used at CIAT is as follows: all hybrid seeds are germinated
at CIAT headquarters where adequate care is provided for seed-
lings. Six months after germination each seedling is cut into
two stakes; one remains in CIAT and the other goes to the se-
lection site. This approach permits that virtually all gene-
tic variability created by a cross will be presented for the
initial selection at the target region (Hershey, 1983).

In Brazil, the first hybrid generation is grown in CNPMF.
One year after planting a mild selection is practiced among
and within families and each selected genotype is cloned into
five stakes. Each cutting is sent to a different selection
site.

In Zaire, Singh (1980) suggested that seedlings should be initially selected for CBB and CMD resistance during the rainy season and the survivors be later screened for CGM and CMB during the dry season.

At IITA seedlings are first screened for disease and pest resistance and only the surviving genotypes are unprooted and evaluated for root yield and other characteristics (Hahn *et al*, 1979).

The first clonal selection is practiced when genotypes are planted in single rows of 5-10 plants. Kawano (1980) reported that single roow root yield had no correlation with bordered plot root yield. Since harvest index of single rows showed a higher correlation with root yield of bordered plots, it was suggested that harvest index in single rows was a better selection criterion than yield itself. Lozano *et al*,(1983) argued that under high productivity environments, selection for harvest index in early stages could be more efficient, but in low yielding environments selection for root yield, along with reasonable harvest index, was a better strategy.

Row selection at CNPMF takes into consideration root yield and quality, harvest index, disease and pest resistance and plant architecture.

At IITA, the first clonal generation is evaluated in a reliminary yield trial with single rows of 3-5 plants. A standar cultivar is planted every ten rows as a check. Evaluation is for disease and pest resistance, plant architecture and general vigour. Only selected clones are evaluated for dry matter and other traits (Hahn *et al*, 1979).

Bordered plot selection begins at the second or third clonal generation and becomes more effective at later generation when the amount of planting material permits adequate plot size, number of replications and number of test locations.

Hand pollination and pedigree selection have some limitations such as high cost, due to the large amount of hand labor required; relative inefficiency in breaking undesirable linkages, because only one cycle of recombination is allowed; and inefficiency in combining a large number of desirable traits into a single genotype, because two particular parents usually do not have all necessary genes and very often hybrid progenies are too small to include all possible recombinants (Byrne, 1984).

Interspecific Hybridization

Since most species of the *Manihot* genus can be easily

100

crossed with cultivars of *Manihot esculenta*, the entire genus may be considered a common gene pool from which desirable alleles can be drawn for cassava improvement (Hahn *et al*, 1973).

Most programs of interspecific hybridization were conducted in Africa. Breeding for resistance to CMD was started in East Africa in 1937. No resistance was found in the cultivated species, but the progenies of *Manihot esculenta* x *Manihot glaziovii* showed promise (Hahn *et al*, 1979).

In Madagascar breeding for resistance to CMD was initiated in 1940. Resistance was not found after repeated crosses between *Manihot esculenta* x *Manihot glaziovii* (Hahn, 1978).

In Nigeria breeding for resistance to CMD started in 1955 with the introduction of clone 58308 from east Africa. This clone has showed stable resistance for several years, but also low root yield and poor root quality (Hahn *et al*, 1979).

A few other species have been used in crosses with *Manihot esculenta* with variable results. Jennings (1959) reported that hybrids between *Manihot esculenta* x *Manihot melanobasis* where often superior in seed set and root yield to intraspecific crosses.

In Brazil, an attempt to transfer CBB resistance from *Manihot glaziovii* was discontinued at IAC (Instituto Agronômico de Campinas) in Sao Paulo. No resistant clones with good agronomic performance were developed.

The backcross method has been the most common procedure used for incorporation of CMD resistance into cultivated cassava (Singh and Hahn, 1982). Although resistance was transferred, no overall agronomic improvement was observed in the hybrid progenies.

According to Hahn *et al* (1973) a sound methodology for efficient introgression of exotic germplasm into cultivated cassava is needed, especially when traits to be incorporated are quantitatively inherited. The major problem is inclusion of a few special features of the wild forms, without disorganizing the desirable gene complexes build up in superior cultivar.

Other methods such as modified convergent crosses and three-way crosses have been proposed, b-t results were not reported (Hahn, *et al*, 1973 and Singh and Hahn, 1982).

Population Improvement

The probability of a superior recombinant type to appear
in a progeny of a given cross increases when the parents have
a high frecuency of desirable alleles. As was stated before,
very few geno types within the cassava germplasm have this
quality. Therefore, parental populations must be improved for
increase of efficiency of breeding programs.

Recurrent selection has been reported to be the most ef-
ficient procedure for improvement of cassava base populations
(Hahn, 1978; CIAT, 1982; Byrne, 1984). The objectives of most
recurrent selection programs are to increase the gene frecuen-
cies for traits such as high root yield, good root quality,
disease and pest resistance, tolerance to soil and climatic
stresses and stability of production across environments (Hahn
*et al*, 1980 and CIAT, 1981).

The first step of recurrent selection procedure is synthe-
sis of the original source population. Success in developing
a good population depends on selection of adequate parents with
high breeding values. Parents for most existing programs have
been selected based on clonal performance (CIAT, 1982a; Byrne,
1984). According to Hahn *et al*, (1979) two to three generations
of random mating without selection are necessary for population
synthesis.

Synthesis of original populations and later recombinations
are done is isolated open pollinated crossing fields. In CIAT
recombination is done in an isolated polycross with several
replications (CIAT, 1981). Populations with larger genetic var-
iability may be developed by using wild species in crossing
plots (Hahn *et al*, 1979).

Cassava is not well suited for open pollination schemes
where random pollination is required, because flowering time
and pollen production differs widely among genotypes. For ef-
ficient recombination a good management of flowering is requir-
ed (CIAT, 1981). Progenies resulting from each recombination
cycle are evaluated and selections recombined again to form a
new population.

Introgression of desirable genes, present in otherwise
undesirable parents, into superior populations can be done by
planting the unadapted parents as border rows of crossing blocks.
They must be emmasculated regularly for preventing contamination
of the gene pool. Progenies from the crosses are evaluated
and the procedure is repeated with the selections (CIAT, 1981).

Hahn *et al* (1979) reported that no critical information is
available on population size and selection intensity adequate
for recurrent selection in cassava. The suggested a selection
intensity of 5-10% for the first cycle and 25-30% for subsequent

cycles. The selected portion should contain 500-1000 plants to avoid loss of favorable genes.

In Brazil there are no reported attempts of recurrent selection for cassava improvement. However, CNPMF's breeding program will initiate a half sib recurrent selection in 1985. The original population will be sinthetized by intercrossing ten selection genotypes of different origins and good performance in Cruz das Almas. If the scheme proves efficient, the frecuency of desirable alleles should increase in subsequent selection cycles, and the probability of identification of superior genotypes will also increase.

## Non-conventional Procedures

### Polyploidy

Graner (1942b) applied colchicine to the apical meristem of cassava and was successful in developing tetraploid plants (4n = 72) which exhibited larger stomata than normal diploids. However, tetraploids had retarded plant growth and did not yield as well as diploids.

Other reports stated that tetraploids were more resistant to CMD and had higher protein content than diploids (Byrne, 1984).

Triploids (3n = 54) obtained by crossing female tetraploids with male diploids, seemed to offer some hope of higher root yield than their parents.

### Mutation

Radiation has been used in cassava cuttings, potted plants, seeds and pollen grains to increase genetic variability. In general, results were an increased mutation rate and reduction in plant growth, even though some vigorous mutants have been observed. Most mutants produced have not been agronomically useful (Byrne, 1984).

### Tissue Culture

Embryo culture, as a propagation technique for difficult to germinate species has been successfully done with some wild *Manihot* species. As for pollen and anther cultures, only callus and root regeneration has been observed. Somaclonal variation and cell fusion still need a system for protoplast regeneration and selection of hybrid fusion cells (Byrne, 1984).

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# INHERENT AND ENVIRONMENTAL FACTORS RELATED TO CASSAVA
# VARIETAL SELECTION[1]

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ABSTRACT

The relatively uncomplicated flowering and pollination hab-
it of cassava leads to easy creation of hybrids. Vegetative pro-
pagation greatly facilitates handling of genetic material in
this crop. In segregating populations or single-row trials,
harvest index can be used as the most important selection cri-
terion for the final yield although effort has to be made to
maintain good balance between harvest index and canopy density.
Cassava and most, if not all, of its major diseases constitute
horizontal pathosystems in which the resistance is characteriz-
ed by slow disease development and controlled by additive poly-
genes. Thus, durable resistance may be obtained with relative
ease. The great majority of important agronomic characters are
controlled by additive polygenes, thus, a straightforward hybri-
dization scheme followed by simple phenotypic selection is ef-
fective in creating desirable recombinants.

While creation and manipulation of genetic materials in ex-
periment stations are relatively easy, incorporation of exotic
germplasm into hybridization and selection schemes is recommend-
ed, and special care must be taken in defining selection sites
and accompanying cultural practices. Selection sites must be
located in the most representative cassava production areas and
the cultural practices of the selection plots must be adjusted
within the reach of the average farmers. If the breeder is giv-
en a choice between easy and difficult growing conditions for
his selection site, he is encouraged to take the latter.

The style of breeding program in a given crop is primarily
determined by the botanical characteristics of the species such
as pollination and reproduction habits. Dealing with crops such

as cassava to be adapted to a variety of marginal conditions, the selection scheme is further complicated by the difficulty of grappling with the bulk of farming situations that have partial or no access to modern cultural practice technology.

This paper presents factors related to defining a breeding and selection scheme as well as experiences related to defining selection environments in cassava.


BIOLOGICAL NATURE


Cassava is a monoecius species with the stigma and anther usually separated in different flowers on the same plant. The male and female flowers seldom open simultaneously on the same branch; however, it is common that the female and male flowers on different branches of the same plant open at the same time. There seems to be no physiological or genetic mechanism to prevent self-pollination and cross-incompatibility has not been observed. Strong inbreeding depression is observed in characters such as root yield and total biological yield (Kawano, 1978). This strong inbreeding depression, in addition to the vegetatively propagated nature of the crop, is the biological mechanism through which high heterozygosity of the species is maintained (Kawano *et al*, 1978).

Vegetative propagation is of great advantage to breeders. Once a favorable genotype is obtained, the genotype can be multiplied indefinitely. Character expression at the seedling stage is well correlated with that at the later clonal generations (Kawano, 1978). Early studies on cassava breeding (Koshy 1947; Chandraratna and Nanayakkara, 1948; Bolhuis, 1949; Arraudeau, 1962; Magoon, 1967) presented occasional difficulties such as non- or scarce flowering of some clones, low seed setting on some female parents, low germination, etc. However, they by and large agreed with our own experiences that cassava is one of the easiest among major crops in creating and handling recombinant genotypes.


PHYSIOLOGICAL NATURE


A food crop is genetically improved through the improvement of either total dry matter production or harvest index, or both. Harvest index is the proportion of economic yield to the total biological yield of a plant. In cassava, it is the proportion of root weight to the total plant weight. Total biological yield represents the crop's photosynthetic efficiency while harvest index represents the efficiency of the crop to convert photosynthesized products into an economically valuable form.

Kawano and Jennings (1983) evaluated the relative importance of harvest index and total plant weight to yield at different levels of environmental productivity in various major food crops. They is found-out that harvest index is important across all the yield levels in cassava (Fig.1). The relative importance of total plant weight tends to be greater in the low than the high yielding environments. This contrasts with rice, wheat, barley, oats, or groundnut, in which total plant weight is more important under low-yielding environments while harvest index is more important under high-yielding environments (Table 1). In maize, total plant weight is important throughout all the yielding levels while harvest index is important only under high yielding levels. In field beans, total plant weight is important throughout all the yielding levels while harvest index is not important the yielding level. Thus, in cassava, manipulation of harvest index is a key to yield breeding/selection not only under high but also under low yielding environments.

With this background, selection for higher harvest index has been the main strategy of the CIAT cassava varietal improvement program. However, we noticed that overemphasis on harvest index might lead to neglecting the importance of total plant weight. The balance between total plant weight and harvest index may be highly important especially under low-yielding environments.

Observing two successful cases of yield selection, I noticed that harvest index might not necessarily be correlated negatively to stem and leaf weight and there might even be a possibility of manipulating harvest index without changing stem and leaf weight (Table 2). If this were possible, 33% improvement in harvest index (from .50 to .67) would result in 100% increase in root yield. This, of course, sounds a little too sweet. Yet, the indication that harvest index is not automatically negatively correlated with stem and leaf weight, which represents canopy density of photosynthetic capacity, is encouraging. Keeping eyes simultaneously on harvest index and canopy, the breeder may arrive at a good balance between photosynthetic capacity and harvest index, avoiding a pitfall of selecting very high harvest index genotypes with low assimilation power.

Several good studies on physiological factors related to canopy formation and harvest index (Cock, 1975; Cock *et al*, 1979; Tan and Cock, 1979) are available. One factor which seems to have escaped their attention is the leaf area ratio as a function of leaf size and internode weight. I seem to observe compact canopy with short internodes and high leaf area index as opposed to tall canopy with long internodes and low leaf area index. The former may lead to the improvement of harvest index without losing photosynthetic power. These factors merit further attention from physiologists.

TABLE 1.  RELATIVE IMPORTANCE OF HARVEST INDEX AND
          TOTAL BIOLOGICAL YIELD IN MAJOR FOOD CROPS
          UNDER LOW AND HIGH YIELDING ENVIRONMENTS -
          SCHEMATC PRESENTATION*.

|  | Yield Limiting Factor In | |
|---|---|---|
|  | Low yielding environment | High yielding environment |
| Cassava | A,B | A |
| Rice, Wheat, Barley Oat, Peanut | B | A |
| Maize | B | B,A |
| Field bean | B | B |

A:    Harvest index

B:    Total Biological yield

*     Adapted from Kawano and Jennings (1983)

TABLE 2.  COMPARISON OF YIELD PARAMETERS IN TWO CASSAVA VARIETAL TRIALS

|  | Fresh root yield (t/ha) | Fresh biological yield (t/ha) | Fresh leaf & stem weight (t/ha) | Harvest index (t/ha) |
|---|---|---|---|---|
| TRIAL I* | | | | |
| Five best clones | 41.6 | 61.5 | 20.0 | .68 |
| Control (local cultivar: Rayong 1) | 28.9 | 49.8 | 20.9 | .58 |
| % advantage over control | 44 | 23 | -4 | 17 |
| TRIAL II** | | | | |
| Five best clones | 59.3 | 86.5 | 27.2 | .69 |
| Control (local cultivars: Golden Yellow and Kadabao) | 32.0 | 60.8 | 28.7 | .52 |
| % advantage over control | 85 | 42 | -5 | 33 |

\*    Conducted at Rayong Field Crop Research Center, Thailand in 1983/84.  16 clones were tested.  (Data source: Kawano, K. and Charn Tiraporn, Dept. Agr., Thailand).

\*\*   Conducted at PRCRTC in Leyte, Philippines in 1983/84.  74 clones were tested. (Data source: Apilar, E. and K. Kawano, PRCRTC).

COMPETITION AND EVOLUTION OF CULTIVARS

Studies of intergenotypic competition in cultibated species
lead to a better understanding of the evolutionary background
of a crop and the physiological basis of plant yield.  Of prac-
tical interest is the behavior of different genotypes in mixed
populations in plant breeding and selection programs.  Competi-
tive ability is defined as the ability to perform better than
planted in association with other genotypes.  The essential
part of intergenotypic competition is the competition for light
interception.  Hence, the genotypes with a high harvest index
are weak competitors because of the relatively fewer resources
allocated to stem and leaf expansion and those with large stem
and leaf weight are strong competitors.  These principles well
demonstrated in rice (Kawano and Tanaka, 1967; Jennings and A-
quino, 1968; Kawano *et al*, 1974) and also in cassava (Kawano
and Thung, 1982; Kawano and Jennings, 1983).

In cassava, competitive ability is highly correlated with
stem and leaf weight (Fig.2) and negatively correlated with
harvest index (Fig.3).  Because harvest index is highly corre-
lated with root yield in monoculture (Fig.1), competitive abil-
ity in negative correlated with root yield in monoculture (Fig.
4), while, by definition, it is less negatively correlated with
root yield in mixed culture.  Harvest index is relatively stable
between mono- and mixed populations while root weight of the
same genotype can change dramatically between the two popula-
tions due to the competition effect.  As a result, harvest in-
dex in mixed culture is more highly positively correlated with
root yield in monoculture than root yield in mixed culture is
with root yield in monoculture (Fig.5).  It can be concluded
that at early stages of selection trials, in which genotype eva-
luation is based on individual plants or clones planted in mix-
ture with other genotypes, harvest index is a better selection
criterion for root yield in monoculture than root weight itself
(Kawano *et al*, 1982).

Land races or traditional cultivars, which often show res-
pectable performance within their adapted environments with
their accustomed cultural practices, are the results of natural
selection and farmer's half-unconscious selections for thousands
of years.  If the competitive ability of the crop is positively
correlated with economic yield in production field, such as in
the case of field bean (CIAT, 1977), the present day breeder of
the crop would have to work basically in the same path of natur-
al and farmer selection.  Hence, modern efforts to improve the
field may represent only a fraction of what has been achieved
during thousands of years.  Consequently, a quantum jump in
yielding ability is not likely.

In cassava and its wild relatives, roots are not an organ
for reproduction because seeds and stems are the means of pro-
pagation.  Natural selection favors genotypes with large stem

bulks and modern effort to improve yielding ability in monoculture through higher harvest index is contrary to the general direction of natural selection. This suggests that the potential of cassava germplasm to respond to modern breeders' efforts is largely untapped. Consequently, a quantum jump in yielding ability is expected.

## DISEASES AND PESTS

Among the factors that influence the productivity, biological constraints, especially diseases and pests, contribute to low productivity. In a review of numerous cases of crop disease interaction, Robinson (1976) distinguished between vertical and horizontal pathosystems. He concluded that vertical (non-rate-reducing, monogenic) resistance, frequently present in sexually propagated annual species, often results from plant breeders disturbing evolutionarily balanced systems. Nature and less meddling by man, favored the development of horizontal (rate reducing, polygenic) resistance in vegetatively propagated perennials. This suggests that vegetatively propagated perennial crops such as cassava are more easily bred for durable disease resistance.

Our experience coincides with this general view. Cassava bacterial blight (CBB), caused by *Xanthomonas campestris* pv. *manihotis* is one of the most devastating diseases of cassava. CBB on infected leaves of resistant clone spreads slowly while on susceptible clones it spreads rapidly causing defoliation and stem death of (Fig.6). Resistance is a quantitative trait and cultivar order of resistance is stable over many years and locations (Umemura and Kawano, 1983). Cassava resistance to superelongation disease caused by the fungus *Elsinoe brasiliensis*, another serious disease of cassava, is also characterized by slow rate of disease spreading (Kawano *et al*, 1983). Inheritance of cassava resistance to this disease is also quantitative (Fig.7). Aside from CBB and superelongation, there are many diseases and pests that can cause serious damage to cassava production. We are optimistic that cassava resistance to most of these are similar to resistance to CBB or superelongation, thus adding relatively little complication to the breeders' work.

IITA (International Institute of Tropical Agriculture) and CIAT have been successful in identifying sources of resistance to most of the major diseases and some of the major insects. Some national programs, such as the one at the Central Tuber Crops Research Institute in India, have identified resistance sources to their major diseases and are in an advanced stage of utilizing them. I consider that the ways to incorporate disease and pest resistance into yielding ability and adaptation are well indicated except for some pest problems in which

113

genetic resistance is weak or yet to be found.

## INHERITANCE OF MAJOR AGRONOMIC CHARACTERS

Our analyses in the past ten years suggest that virtually all the important, agronomic characters are controlled by a polygene system. Additive gene effects are predominant and narrow sense heritability is high in the majority of these characters (Table 3), such as harvest index (Fig.8), root dry matter content (Fig.9), and CBB resistance (Fig.10). These suggest that a straightforward hybridization scheme, no matter whether it is controlled- or open-pollinations,followed by simple phenotypic selection is effective in creating desirable recombinants.

## GERMPLASM CENTER AND DECENTRALIZED BREEDING PROGRAM

Cassava originated and completed the major part of its evolution in Latin America. Cassava was widely distributed throughout the lowland tropics of Latin America before the arrival of the Europeans in the 15'th century, but did not exist outside the continent. However, in the post-Colombian era, the crop spread rapidly, first to Africa and later to Asia.

Germplasm variation of crop species is the richest in the center of origin and diversification of the species. Evolution of disease and pest species that thrive on a crop is parallel to that of the crop species, thus, the number of biological yield constraints is highest in the center of crop origin and diversification (Jennings and Cock 1977).

True to the theory, nearly the entire germplasm variation of cassava exists in Latin America, and the African and Asian germplasm consists of a part of the Latin American germplasm and its local recombinants. A broad spectrum of diseases and pests is observed in Latin America and the number of diseases and insects is less in Africa and especially so in Asia. African mosaic disease seems to be the only major disease of cassava that does not exist in Latin America.

This background makes Latin America a logical location for an international center of cassava germplasm development and the Cassava Program of CIAT was established at Cali, Colombia in the early 1970s. The specificity of African mosaic disease and the overwhelming importance of cassava to the African diet led to the establishment in the late 1960s of the Cassava Program of IITA at Ibadan, Nigeria with the regional responsability in Africa.

114

TABLE 3.  NARROW SENSE HERITABILITY OF MAJOR CHARACTERS

| Character | Range of heritability | Data source |
|---|---|---|
| Root yield | 0.80 - 0.40 | CIAT 1974; 1975 |
| Harvest index | 0.68 - 0.72 | CIAT 1974; 1975 |
| Total plant weight | 0.19 - 0.73 | CIAT 1974; 1975 |
| Root dry matter content | 0.51 - 0.67 | Kawano 1978; Kawano, Goncalves and Cenpukdee unpublished data. |
| Root cyanide content | 0.87 - 1.07 | Kawano, de la Cuesta and Gomez unpublished data |
| Post harvest root deterioration | 0.44 - 0.62 | Kawano and Rojanaridpiched, 1983. |
| CBB resistance | 0.63 | Umemura and Kawano, 1983. |
| Superelongation resistance | 0.60 - 0.79 | Kawano *et al*, 1983. |
| Mite (*Manihot tanajoa*) resistance | 0.78 | CIAT, 1981 |

\*    Given as regression coefficient of $F_1$ population average on mid-parent values.

Edapho-climatic conditions of cassava growing areas vary from country to country and from one area to another within a country. Quality requirements also vary depending upon utilization and location. Any new material for varietal selection has to be throroughly screened for local adaptation and other requirements.

Local germplasm is a result of generations of farmers'selections and an excellent source of adaptation to traditional cultural environments and requirements of the locality. Yet a quantum progress, either in yield or resistance factors, is not expected as long as the breeding program uses only local germplasm, because the local germplasm by nature possesses limited genetic variability. Thus, incorporating Latin American germplasm into local breeding populations is desirable and inevitable.

Latin American germplasm on the whole offers much wider genetic variation but it contains genes for local adaptation in much lower frequencies than the local germplasm.

Consequently, obtaining a recommendable cultivar selected from a small number of clones introduced from CIAT is unlikely. To Asian cassava breeding programs, local selection from massively introduced CIAT seed populations, selection from local x CIAT crosses, or the combination of both becomes the most logical alternative.

Our observation on germination of CIAT and Thai clones in Rayong station seems to support this general tendency. CIAT clones, crossed at CIAT, germinated reasonably well with irrigation or under the normal rainfall of 1984. However, the germination of CIAT clones was extremely low without irrigation under the very scanty rainfall of 1983 while that of the local clones, crossed at Rayong between locally selected cross parents, was acceptable and Rayong 1, a well proven local cultivar, germinated very well under any situation (Table 4). The results support not only localized selections but also hybridization programs by national programs.


SELECTION ENVIRONMENT


One of the greatest difficulties in tropical agricultural research is the transfer of experiment station results to farm production. This difficulty is even greater with cassava whose main areas of commercial cultivations are in marginal agriculture areas.

The twelve year history of CIAT cassava breeding program is also a history of defining selection sites. CIAT headquarters are located in the Cauca Valley of Colombia characterized

116

TABLE 4. COMPARISON IN GERMINATION BETWEEN CIAT AND LOCAL CLONES AT RAYONG, THAILAND.

| Year | Treatment | Clone | Number of genotypes | Average Germination (%) |
|------|-----------|-------|---------------------|-------------------------|
| 1983 | No irrigation | CIAT crosses | 234 | 42.7 |
|      | No irrigation | Local crosses | 135 | 60.4 |
|      | No irrigation | Rayong 1 (local cultivar) | 1 | 86.6 |
| 1983 | Irrigated | CIAT crosses | 165 | 68.4 |
|      | Irrigated | Local crosses | 1323 | 75.8 |
|      | Irrigated | Rayong 1 (local cultivar) | 1 | 89.2 |
| 1984 | No irrigation | CIAT crosses | 1237 | 63.0 |
|      | No irrigation | Local crosses | 1321 | 75.9 |
|      | No irrigation | Rayong 1 (local cultivar) | 1 | 96.1 |

Data source: Field Crop Research Institute/CIAT.

by fertile soils, favorable rainfall pattern and modest tempera-
ture schemes, where very little cassava is commercially grown.
It took us only a couple of years to demonstrate spectacular
yield improvement by breeding and selection at the headquarters,
however, the rejoicing did not last long because soon we found
that the elite materials were useless in more representative
cassava growing areas of the Colombian North Coast where soil
fertility was low and the dry season pressure high. We could
manage to select a different set of genotypes which showed sig-
nificant yield improvement in an experiment station located in
the North Coast. However, even these new elites were not as
readily useful in farmers' fields as we originally expected. We
found that the cultural environment at the experiment station
was far better than that of the farmers, thus, the selection
environment was not correctly representing the farmers' condi-
tions. We suffered from a typical "Experiment station vs. Far-
mers' fields" syndrome (Kawano and Jennings, 1983).

It was after we moved our major selection sites to a more
typical cassava field in the north coast and to one of the most
difficult cassava growing areas in Colombian Llanos, characteriz-
ed by extremely poor soil, long dry season, and a broad spectrum
of diseases and pests, that we started identifying truly useful
genotypes for difficult cassava growing conditions of marginal
areas. One such example is CM 507-37 selected from the Llanos
selection site, which has shown yield superiority both under
low- and high-yielding environments (Fig.11). This group of
genotypes as well as selections from the cassava fields in the
north coast compose the main stream of the CIAT cassava hybridi-
zation program.

The Thai cassava research program had been more intelligent
in locating their breeding headquarters in Rayong Field Crop
Research Center where the soil fertility is generally low, dry
season is long and rainfall is erroneous, thus, well represent-
ing the vast cassava areas mostly managed by small, poor farmers.
Hybrid clones selected in Rayong seem to perform equally well
or even better in less difficult cassava growing environments
outside the Rayong station (Table 5).

We can conclude that selection sites must be located in the
most representative cassava production areas and the cultural
practices of the selection plots must be adjusted to be within
the reach of the average farmers. In the breeder is given a
choice between an easily manageable growing conditions and dif-
ficult growing conditions for the selection site, he is advised
to take the greater challenge of the latter.

TABLE 5.   YIELDS OF SOME PROMISING CLONES UNDER LOW, INTERMEDIATE, AND HIGH YIELDING
ENVIRONMENT IN THAILAND.

| Clone* | Root dry yield (t/ha) | | | |
|--------|----------------------------------------|------------------------------------------------|------------------------------------------|---------|
|        | Low yielding environment (Rayong) | Intermediate yielding environment (Banmai Samrong) | High yielding environment (Khon Kaen) | Average |
| CMR 23-29-15 | 9.2 | 11.6 | 15.1 | 12.0 |
| CMR 23-128-141 | 6.6 | 8.9 | 13.8 | 9.8 |
| CMR 23-149-128 | 7.6 | 8.6 | 11.5 | 9.2 |
| CMR 23-17-251 | 8.7 | 5.7 | 10.6 | 8.3 |
| Rayong 1 (local) | 5.5 | 6.7 | 10.1 | 7.4 |

*    Crossed in 1980 and selected in 1980/81/82/83 at Rayong Station.  (Data source:
Field Crop Research Institute, Thailand).
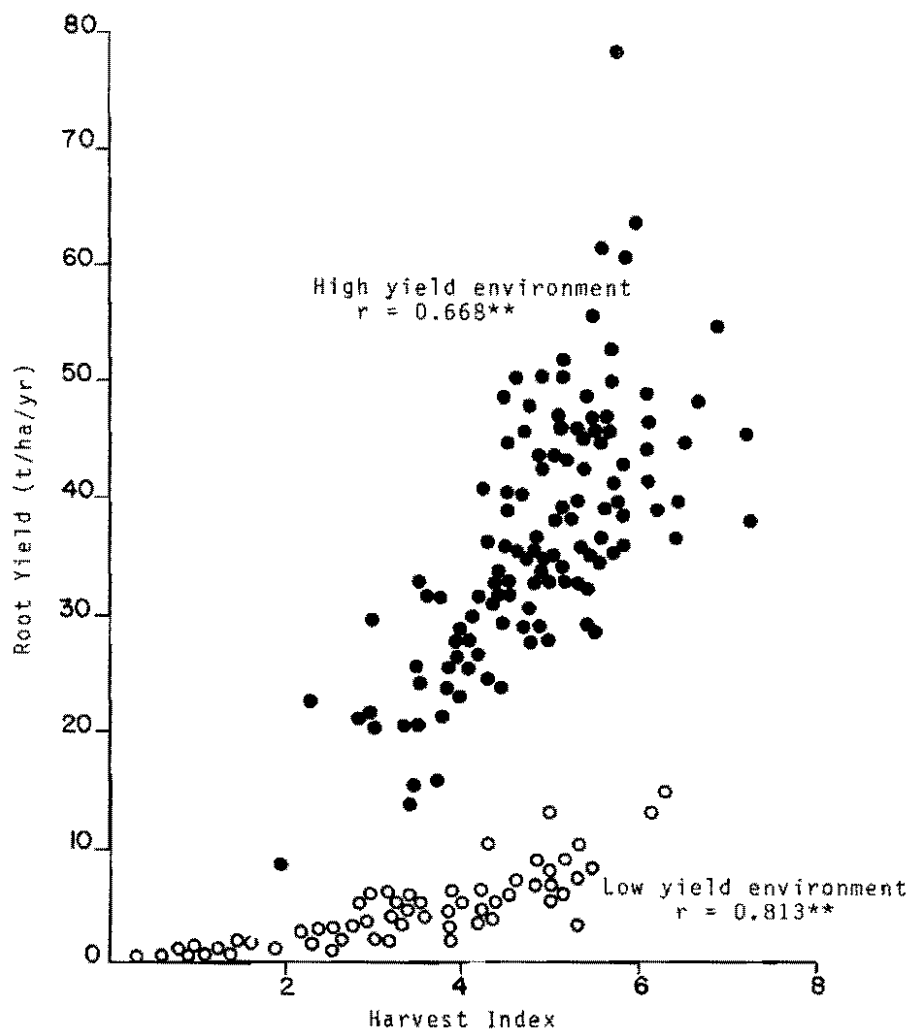
FIGURE 1.  RELATIONSHIP BETWEEN HARVEST INDEX AND ROOT YIELD OF
CASSAVA UNDER HIGH (at CIAT-Palmira) AND LOW (at Ca-
rimagua) YIELD ENVIRONMENT.
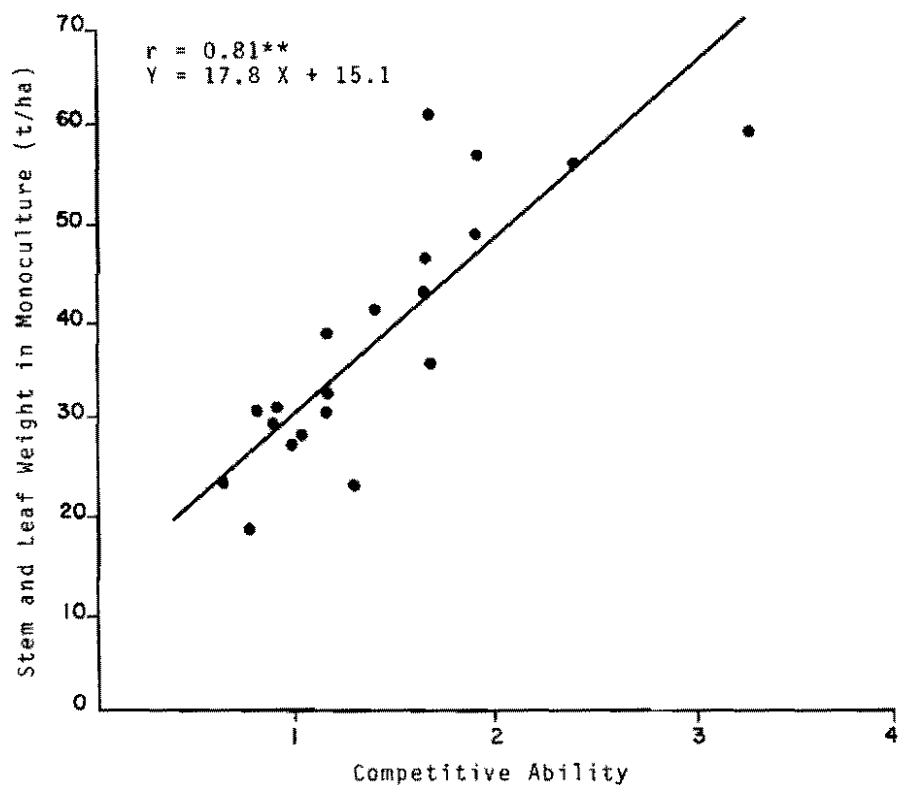
FIGURE 2.  RELATIONSHIP BETWEEN COMPETITIVE ABILITY AND STEM AND
LEAF WEIGHT OF THE SAME GENOTYPE.  (From Kawano and
Thung, 1982).
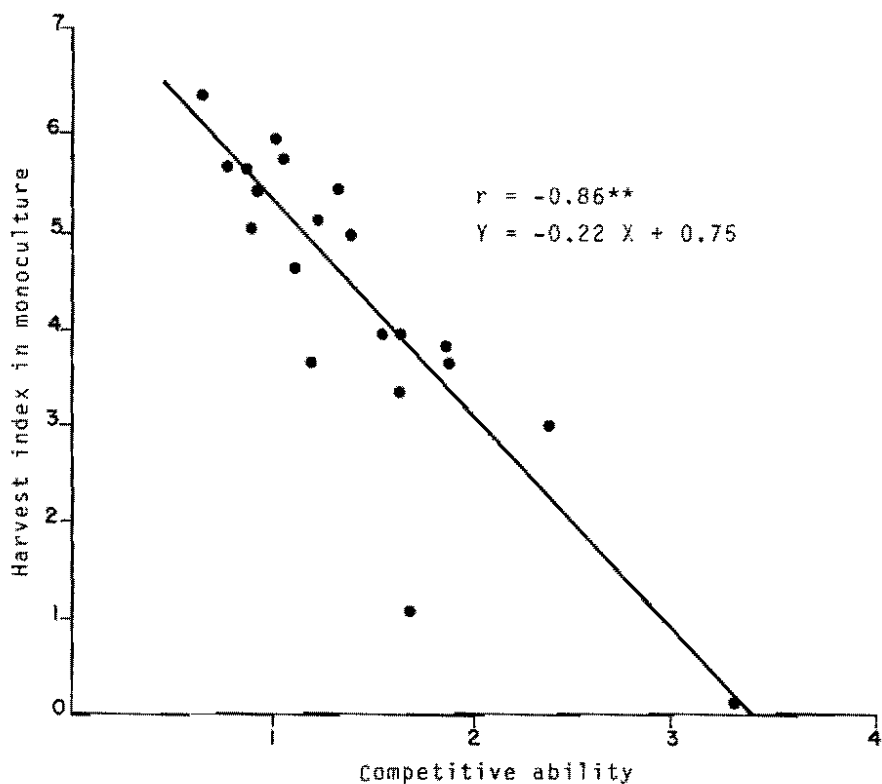
FIGURE 3. RELATIONSHIP BETWEEN COMPETITIVE ABILITY AND HARVEST INDEX OF THE SAME GENOTYPE. (From Kawano and Thung, 1982).
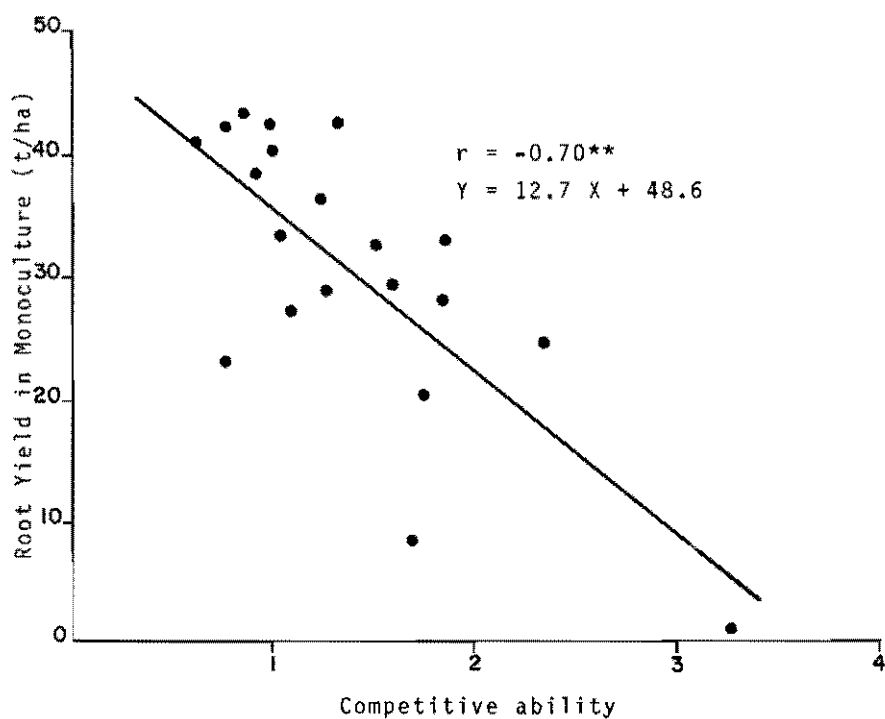
FIGURE 4.   RELATIONSHIP BETWEEN COMPETITIVE ABILITY AND ROOT YIELD
OF THE SAME GENOTYPE IN MONOCULTURE.   (From Kawano and
Thung, 1982).

123
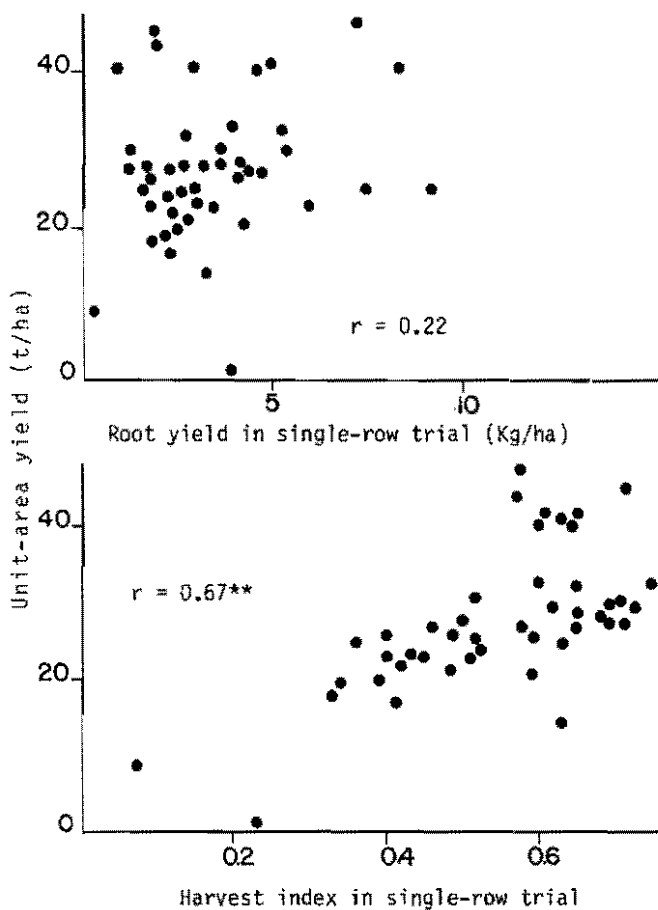
FIGURE 5. CORRELATION BETWEEN ROOT YIELD OR HARVEST INDEX IN SINGLE-ROW TRIAL (1 m row width) AND UNIT AREA ROOT YIELD IN LARGE PLOT TRIAL OF THE SAME GENOTYPE. (From Kawano *et al*, 1982).
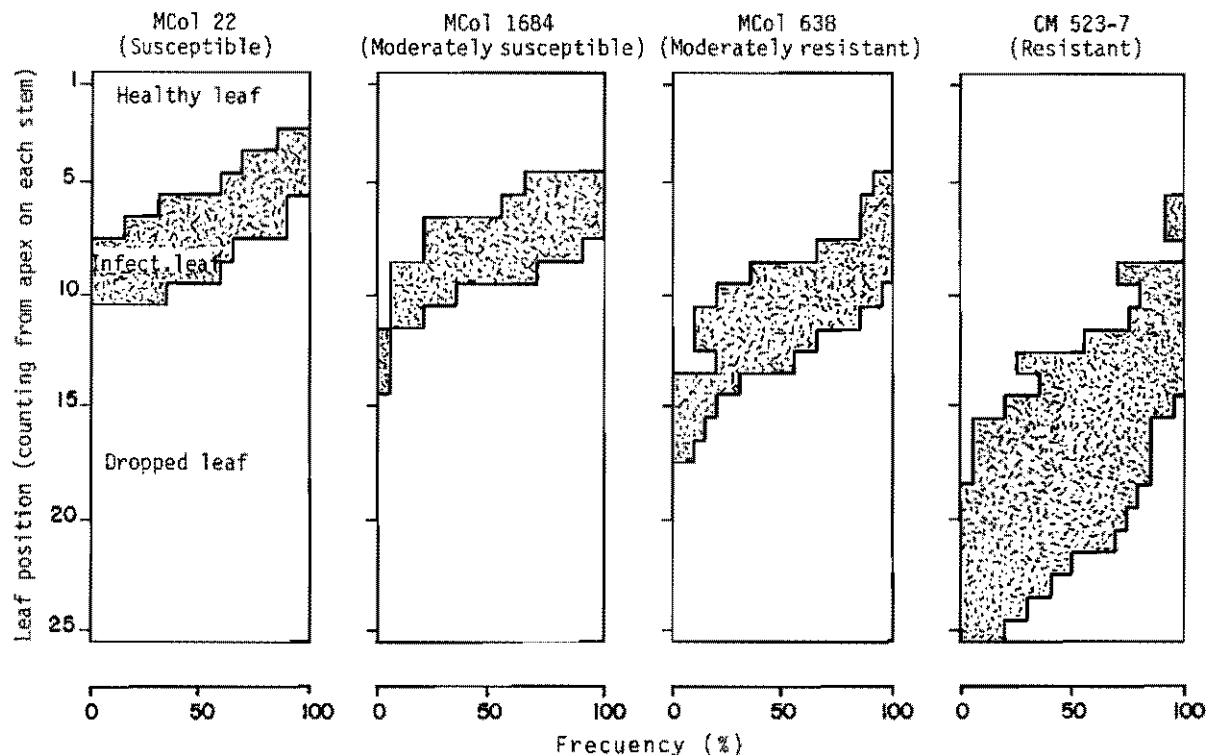
FIGURE 6.  FRECUENCY OF HEALTHY, INFECTED, AND DROPPED LEAVES AT DIFFERENT LEAF POSITIONS IN CASSAVA GENOTYPES OF DIFFERENT CBB RESISTANCE (October in Carimagua, Average of 20 stems).  (From Umemura and Kawano, 1983).
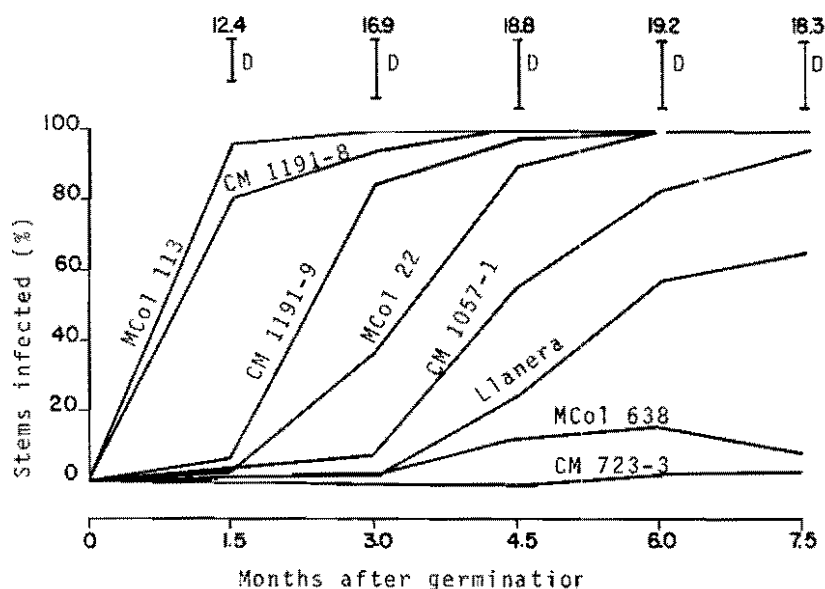
FIGURE 7. SUPERELONGATION DISEASE DEVELOPMENT ON DIFFERENT CASSAVA GENOTYPES AT CARIMAGUA (STATISTICAL D RANGES AT 5% LEVEL FOR MULTIPLE COMPARISON ARE GIVEN AT EACH SAMPLING MONTH). (From Kawano *et al*, 1983).

126
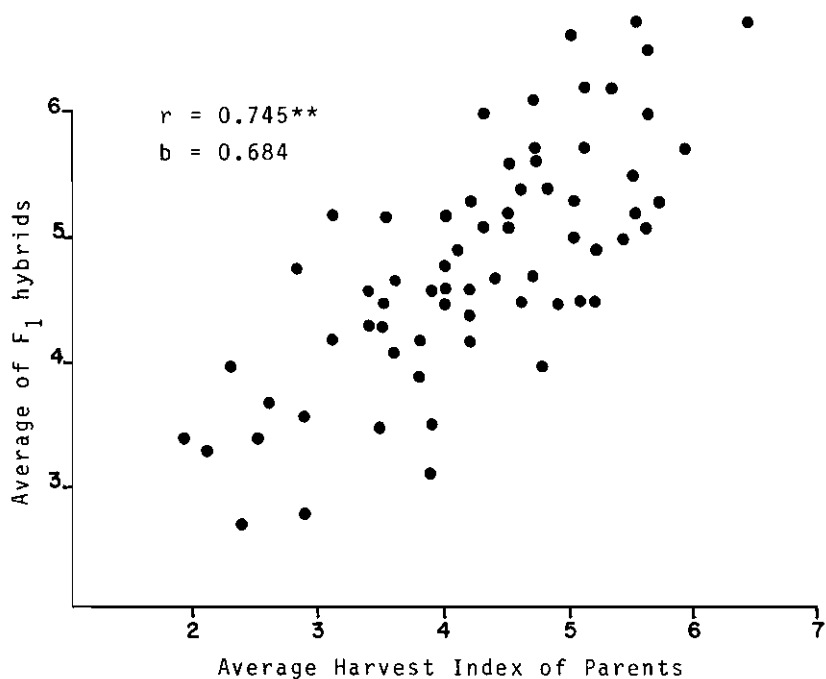
FIGURE 8. RELATIONSHIP BETWEEN AVERAGE HARVEST INDEXES OF
PARENTS AND THE RESPECTIVE $F_1$ HYBRIDS. (From
CIAT, 1975).

FIGURE 9. REGRESION OF $F_1$ AVERAGE AGAINST MID-PARENT VALUE FOR ROOT DRY MATTER CONTENT. (Kawano, Goncalves and Cenpukdee, unpublished).
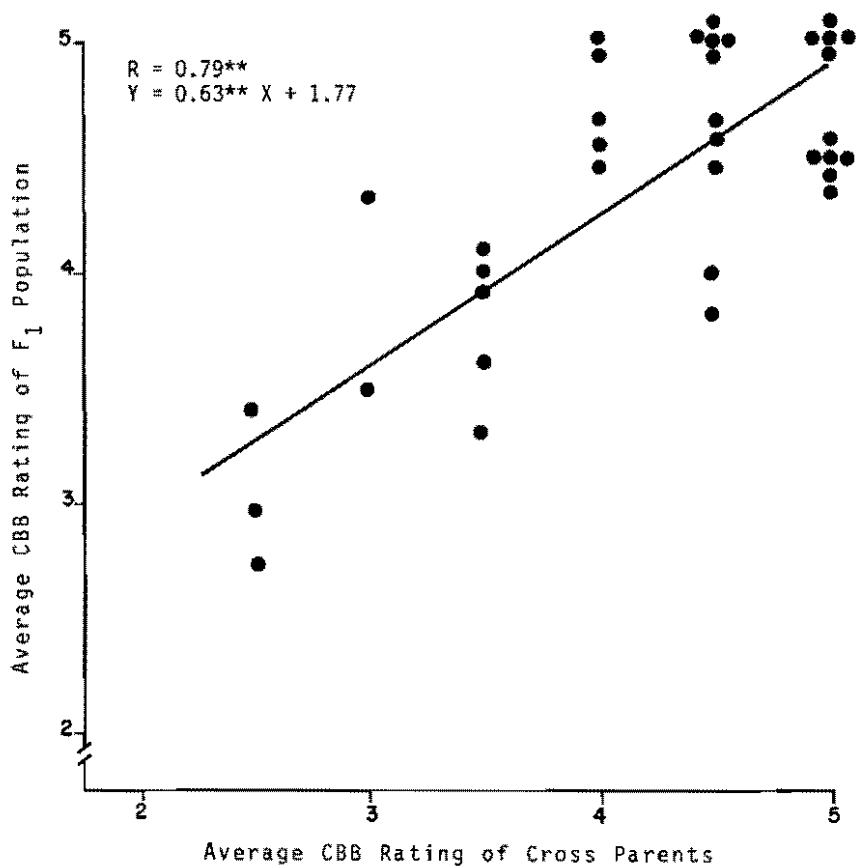
FIGURE 10.   RELATIONSHIP BETWEEN PARENTS AND OFFSPRINGS IN CBB
RATING COMPARISON AMONG CROSSES.   (From Umemura and
Kawano, 1983).

129
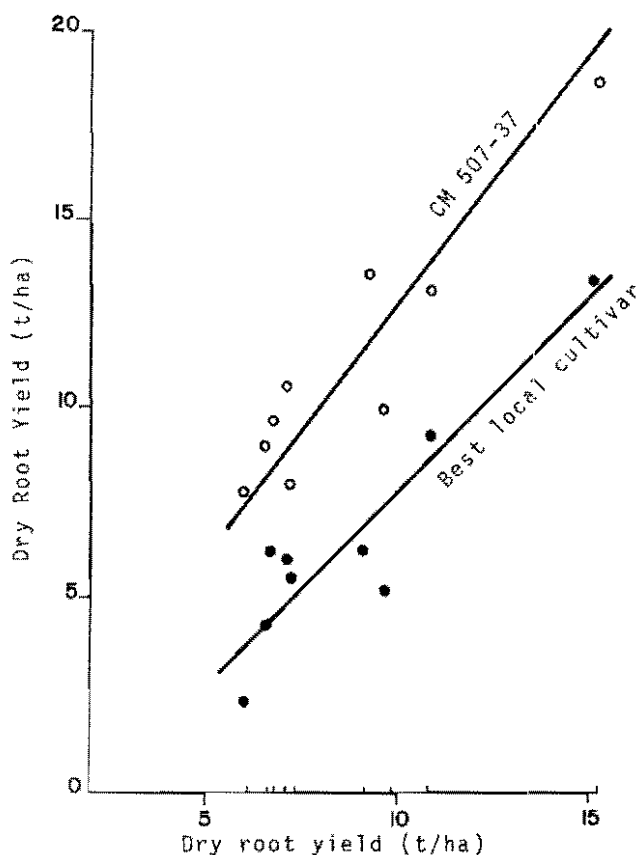
Productivity of trial site (expressed as mean of all the varietal entries at each location)

FIGURE 11.    REGRESSION OF YIELDS OF CM 507-37 AND BEST LOCAL CULTIVARS ON PRODUCTIVITY LEVEL OF THE TRIAL SITE. (From CIAT, 1981).

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131

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# SELECTION FOR YIELD POTENTIAL[1]

Tan Swee Lian*

## ABSTRACT

Yield in cassava is governed by both environmental and in-
trinsic factors.  The need for standardizing cultural and mana-
gement practices in selection trials is emphasized, as this
would help to reduce the variability due to the environment.
Basic understanding of dry matter production in the cassava
plant and its distribution into root storage is necessary to
aid a breeder selecting for high yield potential.

Dry matter production is a function of canopy efficiency,
having a parabolic relationship with leaf area index (LAI).  The
roles of individual leaf size, leaf life, leaf production rate
and branching in relation to LAI are discussed.  As top growth
takes priority over root growth, long leaf life would be bene-
ficial in reducing the need for a fast rate of production of
new leaves, and energy-consuming process.  At the same time,
heavily branched genotypes are undesirable as the dense top
growth shortens leaf life and requires a large proportion of
dry matter for maintenance and growth of stem material.

Harvest index has long been used as a tool in selecting
seedlings and clones for high yield potential.  A high harvest
index implies a genotype in which dry matter storage in the
roots is favoured.  Being highly heritable and easy to estimate,
harvest index is a very practical selection criterion.  It
should, however, be used with some attention given to root yield
in order that the breeder does not end up with small plants of
low yield but high harvest index.  There must also be adequate
top growth throughout the crop cycle to produce the dry matter
for root storage.  As total root number is highly related to
root yield, it is important to select for at least more than 8-
10 roots per plant to ensure that the root sink is not limiting
to yield.  The highly heritable and stable nature of dry matter
or starch content in the roots lends itself favourably to simple

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selection for high dry root yield. In-depth understanding of
the physiological basis of yield in cassava must be attained
for fuller exploitation of its yield potential - either through
cultural or genetic manipulation.

The fundamental ability of cassava to adapt to relatively
poor environments must not be overlooked if future expansion
in cassava production is envisaged. It might be worthwhile to
exploit the yield potential of cassava in special eco-environ-
ments, such as selecting genotypes suited to particular soil
fertility levels, different agro-climatic regions and cropping
patterns.

INTRODUCTION

A valuable source of carbohydrate, cassava has several
important traditional and potential roles to play. I has long
been a staple in various developing nations in Africa, South
America and Asia, and is widely used as an energy component in
the formulation of livestock feed rations. Starch extraction
is probably one of the oldest cassava-based industries from
whence a whole host of related industries have developed, not
the least important of which are the ones producing gasohol
and high fructose-glucose syrups (HFGS). A substantial amount
of interest was aroused in recent years in the petroleum fuels-
substituting potential of gasohol, but has since died down with
the discovery of new oilfields. However, this potential with
its renewable property may yet be exploited in the future. A
growing amount of interest and enthusiasm is being shown at pre-
sent in the sugar-substituting possibilities of HFGS. HFGS is
particularly suited for use in soft drinks, canning and the man-
ufacture of confectionary, and will definitely be of signifi-
cance in countries which produce little or none of their sugar
requirements, and hence have a price differential which makes
HFGS attractive.

Whether destined for human consumption, livestock feed or
starch, high yield and, particularly high root dry matter pro-
duction, is the primary concern of both scientist and farmer.
It has been reported that cassava has the highest potential pro-
duction of calories per hectare per year among tropical crops
(Table 1) (de Vries *et al*, 1967). However, it is not clear
whether the yield of 71.1 t/ha/year was achieved from experimen-
tal plots or from farm plots. Possibly, the figure was a re-
sult of experiemntal yield, considering that the world average
yield is around 8.8 t/ha and the highest mean national yield is
around 18.2 t/ha from India (Singh, 1984). What is evident is
that the full potential of existing cassava germplasm has not
been realized. Experimental yields quite easily reach 50-60
6Tha (Cock, 1974; Kawano, 1978; Chan & Ong, 1981); indeed, some
farmers have reported such yield levels from first-season cassa-

TABLE 1.   MAXIMAL RECORDED YIELDS OF SOME IMPORTANT
           TROPICAL CROPS

| Crop | Yield (t/ha/year) | Energy production (Cal/(ha.day) x $10^3$) |
|---|---|---|
| Rice | 26.0 | 176 |
| Wheat | 11.7 | 110 |
| Maize | 20.0 | 200 |
| Sorghum | 13.0 | 114 |
| CASSAVA | 71.1 | 250 |
| Sweet potato | 65.2 | 180 |
| Banana | 39.0 | 80 |

Source: de Vries *et al* (1967)

va crops on land newly cleared of jungle (Chan *et al*, in press). However, in general, root yields at farm level often fall far below such expectations. This is hardly surprising as cassava is commonly grown in situations in which other crop species have difficulty in surviving let alone produce any economic yield (Cock, 1974; 1979; 1983). A case in point is the huge cassava industry in Thailand, a large proportion of which is based on cultivation in the Northeast region on highly leached gray podzolic soils where other food crops cannot be grown (Sinthuprama, 1984). Minimal or zero inputs are often associated with cassava cultivation among small farmers. In Malaysia, cassava growing is sometimes a part-time operation with the farmer devoting very little time to the maintenance of the crop between planting and harvesting (Chan *et al*, in press).

## APPRECIATING THE FACTORS INFLUENCING ROOT YIELD IN CASSAVA

Economic yield in cassava almost always refers to the weight of the thickened storage roots, specified either as fresh or dry weight. The formation of these thickened storage roots (or storage root initiation) and their subsequent growth in weight (storage root bulking) are both dependent on intrinsic as well as environmental factors.

### Environmental factors

Environmental factors such as temperature, rainfall, solar radiation and soil conditions have strong influences on the physiological processes in and ultimately the yield of a cassava plant (Cock, 1983). In selecting for yield potential in cassava, it is essential therefore that such environmental factors as are within the control of the experimenter be kept as constant as possible. These factors include mainly the agronomic and cultural practices. It has been shown by various workers throughout the tropical belt where cassava is grown that yields vary considerably according to soil nutritional conditions (Takyi 1974a; 1974b; Godfrey-Sam-Aggrey, 1977; Mohan *et al*, 1977; Obigbesan & Agboola, 1977; Chew *et al*, 1978; Chan, 1980). Similarly, cultural practices have varying degrees of influence on yield, e.g. length of cutting (Chan, 1969), part of the stem from which the cutting is taken (Chan *et al*, in press), age of the plant from which the stem is cut, how long the stems have been stored prior to use as planting material (Chan *et al*, in press), planting density (Enyi, 1972a; Mandal *et al*, 1973; Gurnah, 1977; Chan *et al*, in press), depth in planting the cutting, orientation of cutting (Chan, 1969; Takyi, 1974a) the degree of weed control (Doll & Piedrahita, 1977; Godfrey-Sam Aggrey, 1978; Chan *et al*, in press), and length of the crop cycle (Takyi, 1974b, Obigbesan & Agboola, 1977).

136

## Intrinsic factors

Intrinsic factors are those which result from the physical or genetic endowment of a particular clone. Chile physiological characteristics are governed by the genetic makeup of a clone, they are also subject to greater or lesser influence by various environmental factors. Understanding how a certain physiological characteristics or parameter contributes to final root yield in cassava will provide pointers on what constitutes an "ideal" cassava plant in terms of high-yielding capacity. Indeed, some of these parameters if under strong genetic control may serve as selection criteria in the search for high yield potential in a cassava clone.

## Total dry matter production

In a cassava crop is dependent on leaf area, the photosynthesizing surface. The rate of dry matter accumulation, or crop growth rate (CGR), has been found to have a parabolic relationship with leaf area index (LAI), reaching a maximum at an optimum LAI of around 3.5 (Enyi, 1972b; Cock *et al*, 1979; Cock, 1983) (Fig.1). LAI on the other hand is a composite resulting from the product of total leaf number per plant, individual leaf size or area, and planting density.

Planting density in cassava is normally kept at 1 x 1 m, which is near the optimal spacing for root yield in most genotypes for relatively favorable growing conditions. (Chan *et al*, in press). Individual leaf size on the other hand is a varietal characteristic which has a wide range. In one study of six varieties, leaf size ranged from less than 50 cm2 to almost 350 cm2 (Fig.2) (Tan & Cock, 1979b). Leaf size also varies with the time of formation of the leaf (Fig.3)(Cock *et al*, 1979). Leaves formed earlier in the crop's growth tend to be larger than at the end of the season in branched varieties, whereas leaf size in unbranched varieties is less drastically reduced as the crop ages (Fig. 2)(Tan & Cock, 1979b). Some external effects such as drought (Conner, 1980), pest (e.g. thrips), disease (e.g. mosaic (Hahn *et al*, 1979) and anthracnose) and nutritional disorders (e.g. Zn and Cu deficiencies) are known to reduce leaf size. Total leaf number on a plant at any one time is largely dependent on the difference between the rate of leaf production and the rate of leaf abscision (a characteristic which can simplu be described as leaf life) and branching intensity.

## Leaf life

Is another varietal characteristic which varies with the age of the plant when the leaf was formed (Tan & Cock, 1979b). Leaves formed in an older plant are shorted lived. However,

137

unbranched varieties are better able to maintain a constant
leaf life throughout the crop cycle (Fig.4). It is also recog-
nized that shade has drastic effects on leaf life (Cock *et al*,
1979; Tan, 1980), and this may in fact explain why in highly
branched varieties, leaf life drops considerably in the later
growth stages of the plant when there is a greater degree of
intershading among leaves. Leaf life may be shortened by
drought (CIAT, 1976) or disease, but prolonged by cooler tempe-
ratures(Irikura *et al*, 1979)(Fig.5).

Leaf production per apex

Remains fairly constant in unbranched varieties but shows
a gradual decline in rate with time in branched varieties with
little difference among varieties (Fig.6)(Tan & Cock, 1979b).
However, total leaf production, a product of leaf production
per apex and number of apices per plant, changes the picture
entirely: heavily branched varieties have many apices and so
will have a very high rate of leaf production per plant, where-
as an unbranched variety eith its single apex will have a total
leaf production equal to leaf production rate per apex (unless
more than one stem is allowed to develop per cutting (Fig.7).

Finally, branching is a varietal trait definable by three
parameters:

The time to first branching, the rate of subsequent branch-
ing, and the number of apices formed per branching. A variety
which branches early, often, and forms three or four apices at
each branch point gives rise to a heavily branched form with
dense foliage.

CGR has a parabolic relationship with LAI because at very
high LAI's, leaf life becomes shorter and shorter due to shad-
ing. Though the number of leaves per unit land area may be high,
this is maintained by a high turnover rate of leaves.

Total dry matter production or biological yield does not
tell the whole story. Economic yield in cassava usually refers
to the root yield. Although root yield is highly correlated
with total plant weight within a single genotype at various
stages of plant growth (Boerboom, 1978b; Tan, 1980; de Bruijn,
1982), this relationship does not always hold true across geno-
types. In other words, a large plant does not necessarily pro-
mise a high root yield. Harvest index, the ratio of root weight
over total plant weight, is a parameter whcih reflects the dry
matter distribution within the plant in favour of root yield.
In a crop like cassava where the economic yield comes from a
vegetative part, specifically the adventitious roots from a
planted cutting, modified into storage organs, harvest index is
generally much larges than may be expected from a crop whose
economic yield results from fruits or seeds, e.g., grain legumes

138

or cereals. Structurally speaking also, higher harvest indices are possible in root crops since the plant is not required to "hold up" a heavy yield (Coursey & Haynes, 1970).

Harvest index (at harvest as the term suggests) has been found to be one of the most important parameters in the selection for yield potential in cassava. Early work by Kawano (1978) has shown that selecting for high harvest index in seedling plants as well as in clones in single-row evaluation (i.e., the first generation of clonal evaluation) is more effective in identifying high-yielding genotypes than using root yield itself as a selection criterion. This is because seedling and clonal yields are generally unrelated due to the different nature of their storage root systems:

The seedling plant has a tap root system whereas the clonal plant has an adventitious root system. Furthermore, clones in single rows respond differently from those in a stand or population due to differences in plant spacing and competition effects amongst and within genotypes (Kawano *et al*, 1982).

A clone with a high harvest index may be assumed to be a more efficient one physiologically speacking, since most of its dry matter production is channelled towards storage in the roots. However, root storage takes lower priority over stem and leaf or top growth within a cassava plant. Dry matter storage in the roots results from any surplus over dry matter requirements for the production of new leaves (an energy consuming physiological process), maintenance of existing ones, maintenance of tissues in stems and branches as well as weight increase in these organs. This was graphically shown in an experiment where new leaf production was arrested by topping plants. The result was increased dry matter storage in the root (Fig.8) (Tan & Cock, 1979a).

The priority that top growth holds over root storage suggests that in a heavily branched clone with profuse top growth, with the sheer mass of leaves, stems and branches, as well as the high turnover rate of leaves (short leaf life due to heavy shading within the canopy), there will be less dry matter left over for root storage after satisfying top growth requirements than would be the case in a lightly branched clone. This supposition is borne out by an experiment in which a densely branching clone had varying number of branches removed to simulate different degrees of branching. The highest yields came from the lightly branched simulated plant types (Table 2). That an improvement in leaf life might have something to do with these better yields was also evident (Tan & Cock, 1979a). More directly, CIAT (1978) showed that when leaf life was shortened by artificial removal of leaves, root yield was similarly reduced(Fig.9). Indirect evidence is also to be found in the depressive effects of defoliation on root yields (IITA, 1976; Dahniya *et al*, 1981).

TABLE 2.   DRY ROOT YIELD OF MCol 113 WITH DIFFERENT
           BRANCHING PATTERNS

| No. times of branching | No.apices/ branching | Dry root yield(t/ha) | % over control |
|---|---|---|---|
| Control = 4 | 3-4 | 5.5 | - |
| 4 | 3 | 7.3 | 33 |
| 4 | 2 | 10.3 | 87 |
| 0 | 1 | 8.4 | 53 |
| 1 | 3-4 | 8.5 | 55 |
| 2 | 3-4 | 9.8 | 78 |
| 3 | 3-4 | 9.3 | 69 |

Source: Tan, 1980

Selecting for high harvest index therefore ensures that genotypes with excessive top growth are avoided. Nevertheless, recent examination of top growth data in improved new clones (Table 3) suggests that while higher harvest index had seemingly brought about better yields in those clones, it was also striking that their top growth remained virtually unchanged from that of local control cultivars. This seems to emphasize the need to maintain a certain amount of canopy to provide an adequate photosynthetic apparatus for dry matter production. In other words, in striving for higher harvest index, it is still necessary to ensure there remain enough leaves to produce the dry matter for storage in the roots.

Assuming the lack of other limitations to root storage, sink strength is also determined by root number. Total root number has shown high correlations with root yield (Tan, 1981). When root number was reduced to less than seven or eight per plant by clipping at 6 and 12 weeks, root yield declined (Cock *et al*, 1979). Top growth was unaffected by the size of the root sink. In most clones, root number is fixed quite early during the plant's growth (Wholey & Cock, 1974). It can therefore be used as an early selection criterion. There is of late a great deal of interest in genotypes which are able to produce an early root yield (as early as nine or even six months) (Proc. Workshop on "Future Potential of Cassava in Asia and Research Development Needs", 1984). Such short-term cassava varieties will make more productive use of a given piece of land and provide a faster rate of return from planting cassava.

In harvesting for early yield, more often than not a high harvest index at six or nine months is indicative also of that which may be expected after 12 months (Boerboom, 1978a; Tan, 1980). Harvest index changes with time, increasing rapidly in the first six months of growth, thereafter levelling off in its rate of increase towards the end of 12 months (Fig. 10). A high-yielding variety at six months therefore tends to be high-yielding as well at 12 months, except in cases where the rate of increase in harvest index is low but relatively constant throughout the crop growth season. Boerboom (1978b) postulated the use of two parameters to describe the efficiency of dry matter distribution in cassava:

The efficiency of the plant in producing storage roots (ESRP), and the initial plant weight at which storage root production begins (ISS) (Fig.11). Since cassava is harvestable between 6 and 24 months after planting, harvest index may not have reached its constant value at the time of harvest, whereas ESRP as proposed in the dry matter distribution model is a constant throughout time. Thus, ESRP and ISS may be determined at early stages of the growth cycle, e.g., before 6 months after planting. ESRP was also found to be stable over different locations (de Bruijn, 1982). It cannot be denied, however, that harvest index is a more practical tool in selecting for high

141

TABLE 3. COMPARISON OF ROOT YIELDS, TOTAL FRESH PLANT WEIGHTS, FRESH TOP WEIGHTS AND
HARVEST INDICES BETWEEN IMPROVED CLONES AND CONTROLS IN THREE VARIETAL TRIALS

| | Fresh root yield (t/ha) | Total fresh plant weight (t/ha) | Fresh top weight (t/ha) | Harvest index |
|---|---|---|---|---|
| **TRIAL I** | | | | |
| Five best clones | 41.6 | 61.5 | 20.0 | 0.68 |
| Control (local cultivar, Rayong 1) | 28.9 | 49.8 | 20.9 | 0.58 |
| advantage over control | 44 | 23 | -4 | 17 |
| **TRIAL II** | | | | |
| Five best clones | 59.3 | 86.5 | 27.2 | 0.69 |
| Control (local cultivars, Golden Yellow and Kadabao) | 32.0 | 60.8 | 28.7 | 0.52 |
| advantage over control | 85 | 42 | -5 | 33 |
| **TRIAL III** | | | | |
| Four best clones | 28.3 | 48.0 | 19.7 | 0.59 |
| Control (local cultivar, Black Twig | 21.3 | 41.0 | 19.7 | 0.52 |
| advantage over control | 33 | 17 | 0 | 14 |

\*    Conducted at Rayong Field Crop Research Centre, Thailand in 1983/84.  16 clones
     tested.  (Source: Kawano, K. and Tiraporn, C., Dept. Agr., Thailand).

\*\*   Conducted at PRCRTC in Leyte, Philippines in 1983/84.  74 clones tested. (Source:
     Apilar, E. and Kawano, K., PRCRTC).

\*\*\*  Conducted at Ubiyu Plantation, Sitiawan, Malysia in 1982/84.  13 clones tested
     over 2 seasons.  (Source:  Tan S.L., MARDI).

yield potential since ESRP requires data from three or four
harvests to plot the regression slope between root weight and
total plant weight.

To complete the picture of intrinsic yield factors, it
should be mentioned that there is as yet no direct evidence
that photosynthetic rate of single attached leaves is related
to total dry matter production. This is probably because the
relationship, if it exists, is confounded by the total number
of leaves in the canopy, the degree of their intershading and
hence the differences in photosynthetic rates of various levels
withing the canopy. Indeed, Mahon *et al*, (1976) found that
crop growth rate was related to the product of leaf photosynthe-
sis and total leaf area. The rate of photosynthesis of single
attached leaves is not only a complicated parameter to measure,
requiring apparatus of some sophistication, but also a question-
able criterion in terms of practicality and efficiency in the
selection for yield potential at this point in time.

It would be appropriate to mention in passing that diseases
and pests are known to be notorious reducers of yield (Hahn *et
al*, 1979), and that incorporating resistance into clones against
these biotic factors would further remove limitations to the
yield potential of any genotype. Indeed, yield was improved
by two to eighteen fold when resistance to bacterial blight was
incorporated into new clones (IITA, 1976).

TOWARDS REALIZATION OF THE YIELD POTENTIAL IN CASSAVA

What then are the parameters of practical importance in
the selection for high yield potential? Little information on
the genetic control of various physiological parameters and
yield components in cassava is available in published litera-
ture. Heritability estimates on some characteristics of agro-
nomic significance are listed in Table 4.

It is apparent that although broadsense heritability values
($h^2_b$) are generally high for root yield and harvest index, the
narrowsense value ($h^2_n$) is higher for harvest index). This
bears out the finding that harvest index in seedling populations
is highly correlated with yield in clones, and that harvest in-
dex in clones under single-row evaluation relates strongly to
yield in clonal populations. While harvest index without doubt
is a highly useful and usable tool in selection, it would also
be advisable to pay some attention to root yield itself. It
is not uncommon to find genotypes of low vigour (and therefore
low total plant weight due to short stature and poor top growth)
having very high harvest indices when obviously their root yield
are much too poor to consider for selection. It would not do
at all to use harvest index blindly without a thought given to
root yield. It is, therefore, a good idea always to include

143

TABLE 4.  HERITABILITY ESTIMATES OF SOME IMPORTANT AGRONOMIC
TRAITS IN CASSAVA

| Trait | $h^2$ value (%) | b/n* | Source |
|---|---|---|---|
| Root yield | 76 | b | Birader *et al*, 1978 |
| | 79 - 94 | b | Kawano *et al*, 1978 |
| | 87 | b | Tan, 1984 |
| | 40 | n | Kawano, 1977 |
| Harvest index | 79 | b | Birader *et al*, 1978 |
| | 75 | b | Tan, 1981 |
| | 89 | b | Tan, 1984 |
| | 68 | n | Kawano, 1978 |
| Dry matter (or starch) content | 80 | b | IITA, 1981 |
| | 93 | b | Tan, 1981 |
| | 92 | b | Tan, 1984 |
| | 62 | n | Kawano, 1978 |
| Total root number | 69 | b | Birader *et al*, 1978 |
| | 81 | b | Tan, 1981 |
| | 92 | b | Tan, 1984 |
| Plant heigh | 37 | b | Birader *et al*, 1978 |
| | 86 | b | Tan, 1981 |
| | 91 | b | Tan, 1984 |
| Mean root weight (or root size) | 40 | b (?) | Hahn *et al*, 1977 |
| | 54 | b | Birader *et al*, 1978 |

* b - broadsense heritability

  n = narrowsense heritability

144

controls, such as local cultivars or best available commercial cultivars, to set the level of yield that is to be improved. It will then be a simple matter to pick out those genotypes whcih exceed this yield level or at least attain it while having a higher harvest index than the controls. Dry matter content of roots, total root number and plant height have similarly high $h^2_b$ values. Mean root weight is less highly heritable. The strong genetic component controlling total root number suggests its possible application as a selection criterion, especially since it is strongly associated with root yield (Holmes & Wilson, 1977; Maggon & Krishnan, 1977; Birader $et$ $al$, 1978; Tan, 1981; IITA, 1982). From a physiological point of view, selecting for higher root number (more than 8-10 per plant) would ensure that the size of the root sink is not limiting to root bulking and yield. Where cassava is grown for the direct human consumption, commercial root number (referring to roots of at least 15 cm length) is an important consideration. This character appears also to be highly heritable with a value $h^2_b$ =85% (Tan, 1984).

The highly heritable nature of dry matter content (or starch content) is encouraging since economic yield in most cases strives for high dry root yield. As a selection criterion, starch content of roots is practical as it can quite easily be estimated as dry matter content (to which it is highly correlated) or converted from the root specific gravity value (again highly correlated with starch content). Moreover, starch content has been found to be a very stable trait over different eco-environments (Tan, 1984).

It is interesting to note that plant height is a strongly inherited character. Plant height has shown positive correlation with total plant weight (Tan, 1981). It is therefore an indirect indication of total dry matter production, although it must be remembered that high total dry matter need not reflect high harvest index. Plant height together with the appearance or condition of top growth serves the function of qualifying plant vigour.

Although the heritability of leaf life and canopy characteristics still remain to be investigated, observations tend to suggest fairly strong genetic control. The use of leaf life as a selection criterion on its own has doubtful practicality-firstly, because one has to determine which is the best stage of growth at which to measure leaf life, and, secondly, because leaf life is only one of the physiological traits contributing to root yield and so may be expected to be relatively ineffective if selected for by itself. To ensure an adequate top growth for dry matter production, leaf life helps to save on wastage of dry matter in abscised leaves and also consumption of more dry matter in producing new leaves. Perhaps, as a temporary measure until fuller understanding of the inheritance of canopy characteristics and on how they can best be exploited is avail-

able, the condition of the canopy throughout the crop cycle may
be used as an index of its adequacy.  While the canopy must not
be excessive (as in densely branched forms where leaf life is
reduced drastically because of inter-shading), enough foliage
should be maintained throughout the cropping season to ensure
a net production of dry matter for root storage (Doku, 1965),
ideally at LAI around 3.0 - 3.5 when root growth rate has been
found to be maximal (Cock *et al*, 1979; Irikura *et al*, 1979).
This probably calls for intermediate or late branched forms
with light branching as completely unbranched forms more often
than not have difficulty in realizing the optimal LAI's for
maximal crop or root growth.

Needless to say, it makes sense to carry out selections
for high-yielding genotypes as far as possible in those envi-
ronments in which they will ultimately be cultivated.  While
for early stages of evaluation involving large numbers of seed-
lings and clones, this may not always be possible for reasons
of costs and logistics, such trials should be located at least
in areas representative of production regions in terms of soils
and climate.  The final acid test for adaptability will still
be regional trial in the final stages of clonal evaluation of
short-listed selections.  This will help in reducing the gap
between yields achieved at experimental stations and in farmers'
fields.

As more and more comprehensive information in gathered to
provide a better understanding of the physiological basis of
yield in cassava and how individual traits are inherited or in-
fluenced by the environment, we may begin to fully exploit the
yield potential of cassava through genetic as well as cultural
manipulation.  The day may come when yields in excess of 90 t/
ha/year as has been estimated to be physiologically sound and
possible (Cock, 1974) will be realized with ease, not only
under experimental conditions but also in real farm situations.


EPILOGUE


The future of cassava is dependent to a considerable extent
on its traditional ability to survive in relatively harsh or
hostile environments where it faces little competition from
other more economically important crops.  It would therefore be
unwise to select for genotypes which respond to a highly favour-
able environment such as high fertility (with heavy fertilizer
applications) and irrigation.  Selection in this direction would
cause cassava to lose its edge over more fastidious crops.  Per-
haps, we should even look towards extending the frontiers of
cassava cultivation into special eco-environments, such as:

1. Particular nutrient environments. There is evidence of physiological variability in different genotypes in their mineral nutrition with regard to responses to Ca, ammonium and nitrate N (Anonymous, 1981).

2. Different climatic and edaphic conditions. Unfavourable climatic conditions may be bypassed by selecting for short duration or early harvestable varieties, e.g. to avoid the hot and dry climate in central India at certain months of the year (Deshmukh *et al*, 1977). Varietal differences in adaptability to acid peat soils have been observed in Malaysia (Chew, 1974).

3. Intercropping with plantation crops. It would be necessary to select for some degrees of tolerance to shade. Screening studies of 100 cultivars under coconut at CTCRI (1973) succeeded in identifying five with root yields about one-third their usual.

4. For mechanization. To reduce labour costs, a major component in production costs for cassava, particularly for harvesting, it would be necessary to select for suitable plant forms to facilitate cultivation (unbranched? as suggested by Magoon & Krishnan, 1977) and a root shape which ia amenable to mechanical lifting.
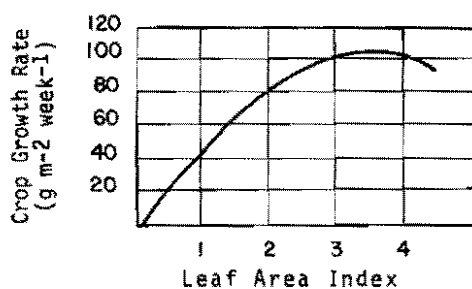
FIGURE 1.   RELATIONSHIP BETWEEN CGR AND
            LAI IN CASSAVA
            Source: CIAT, Annual Report
                    1975.

Note: each column represents a 2-month interval
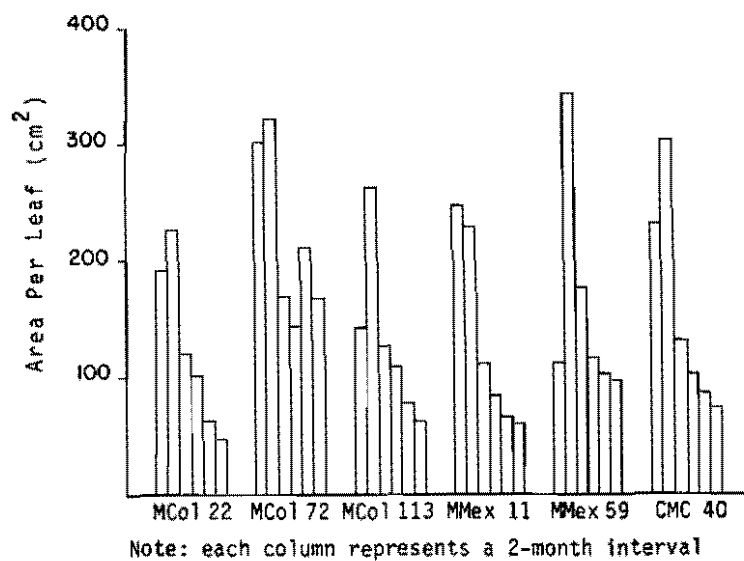
FIGURE 2. LEAF SIZE CHANGES THROUGH TIME IN DIFFERENT
VARIETIES. Source: Tan & Cock, 1979b.
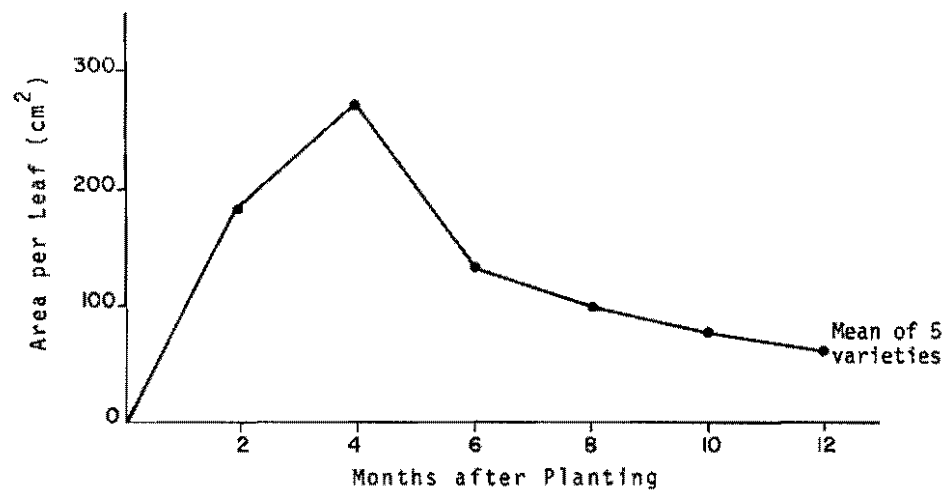
FIGURE 3. LEAF SIZE DIFFERENCES IN RELATION TO TIME. Source: Tan, 1980.
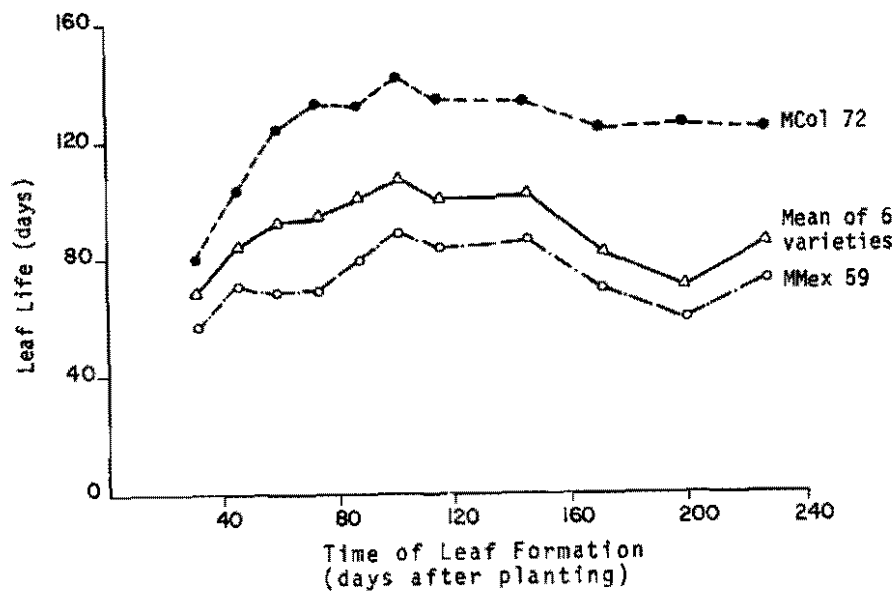
FIGURE 4. LEAF LIFE IN RELATION TO TIME OF LEAF FORMATION.
Source: Tan, 1980
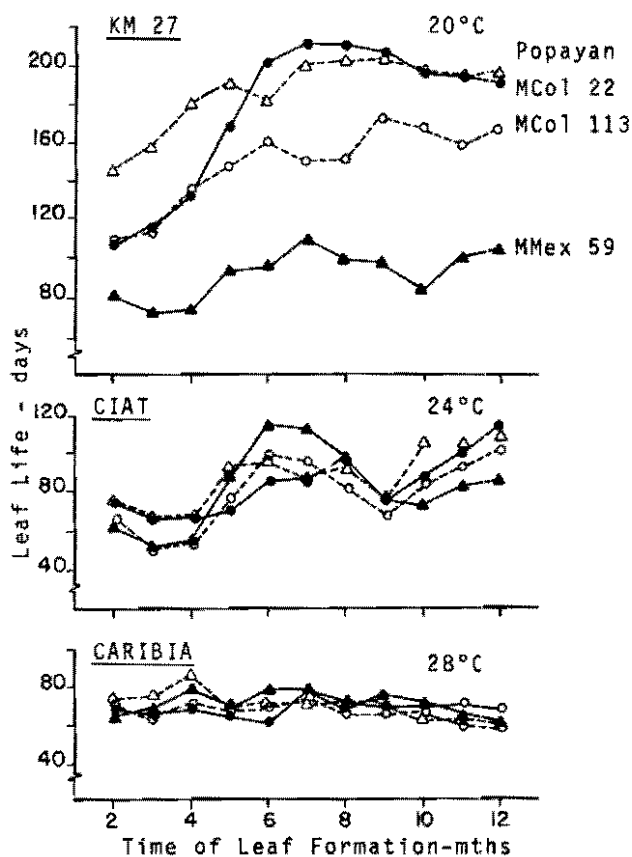
FIGURE 5.   EFFECT OF TEMPERATURE OF LEAF LIFE
Source: Irikura *et al*, 1979
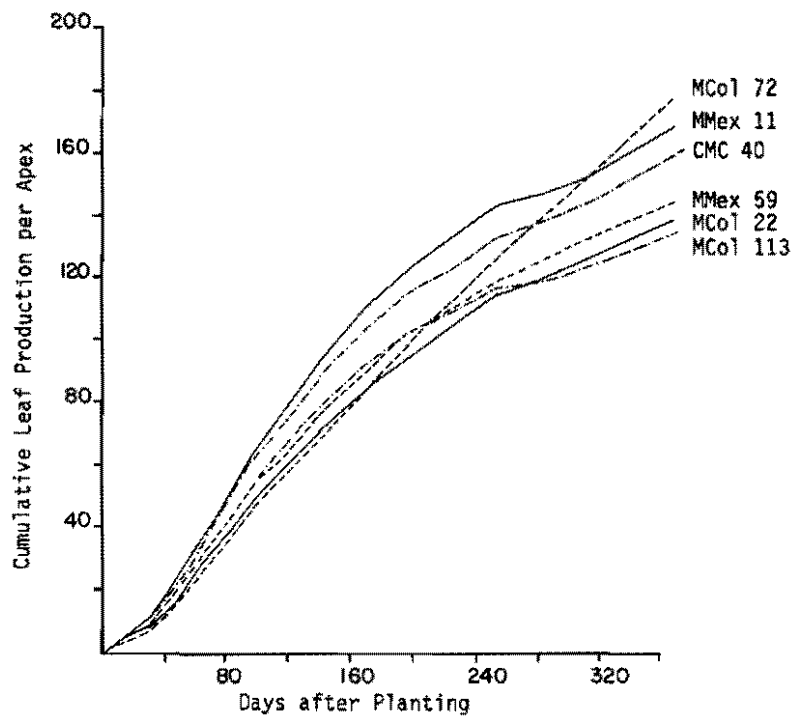
FIGURE 6. LEAF PRODUCTION RATE PER APEX IN DIFFERENT VARIETIES
Source: Tan & Cock, 1979b.
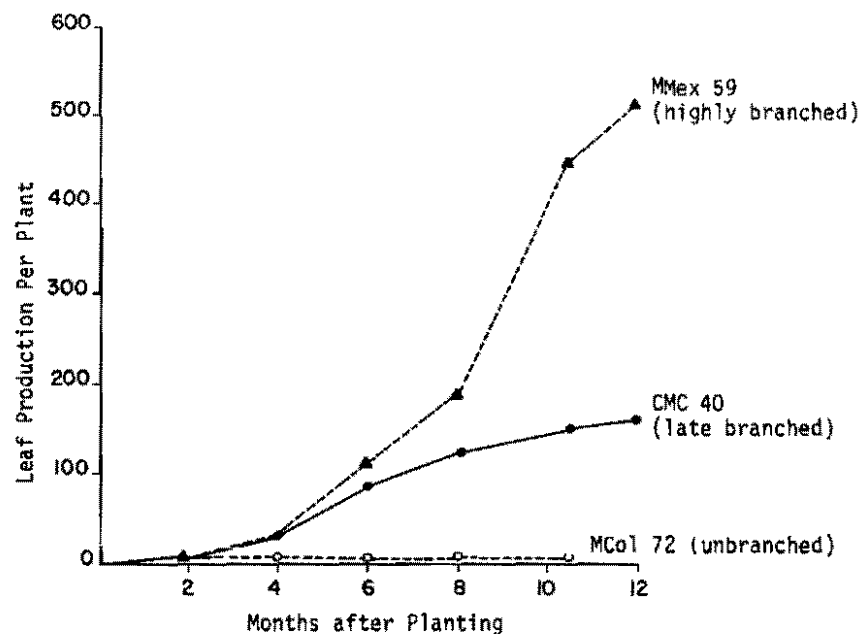
FIGURE 7.  TOTAL LEAF PRODUCTION RATE IN DIFFERENT VARIETIES.  Source: Tan, 1980.
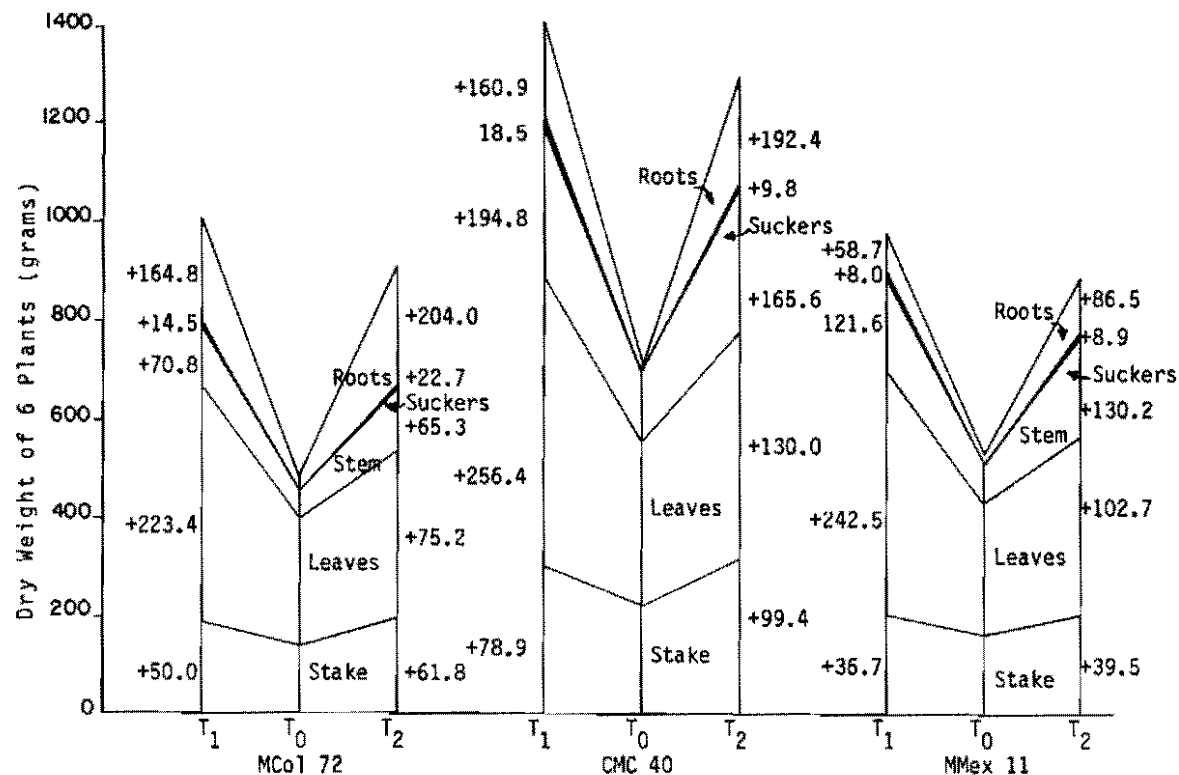
FIGURE 8. DISTRIBUTION OF DRY MATTER IN THREE CASSAVA VARIETIES IN UNTOPPED ($T_1$) AND TOPPED ($T_2$)
PLANTS AFTER 3 WEEKS FROM FIRST HARVEST ($T_0$).
Source: Tan, 1980
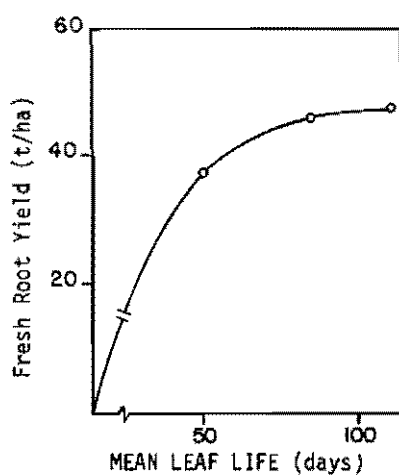
FIGURE 9.  EFFECT OF LEAF LIFE ON ROOT
          YIELD.  Source: CIAT, 1978
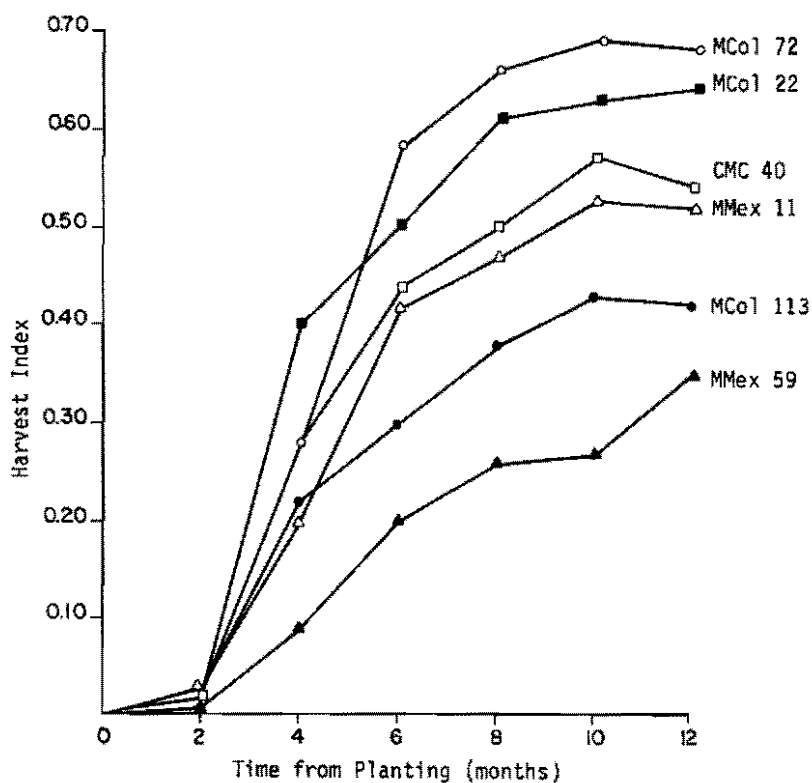
FIGURE 10.  THE RELATIONSHIP OF HARVEST INDEX WITH TIME IN SIX
VARIETIES OF CASSAVA.  Source: Tan, 1980

weight
of roots

ISS

b= ESRP

weight of whole plant

ESRP = Efficiency of storage
root production

ISS = Initial plant weight
when roots bulking begins
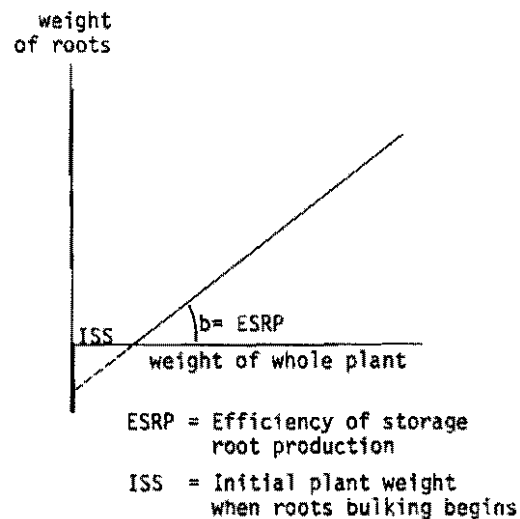
FIGURE 11.  RELATIONSHIP BETWEEN DRY WEIGHT OF WHOLE
PLANT VERSUS DRY WEIGHT OF ROOTS.
Source: Boerboom, 1978a.

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# RAPID PROPAGATION TECHNIQUES FOR CASSAVA[1]

James H. Cock*

## INTRODUCTION

The inherently slow propagation rate of cassava makes it essential to have rapid propagation techniques if clean mother stocks of new varieties are to be rapidly multiplied either for testing or release to farmers. Over the years a number of techniques for propagation have been developed (Chant and Marden, 1958; Wholey, 1974; Kloppenburg *et al*, 1972; Cock *et al*, 1976; Sykes and Harney, 1972; Carpena *et al*). At CIAT we have refined these techniques and developed two basic rapid propagation techniques which we have found to be effective. The first of these, multiple shoot production form two node cuttings is moderately rapid and can be carried out with a minimum of infrastructure. The second technique, using the axillary buds of green stems is considerably faster but requires better infrastructure and more skillful handling of the plant material. Nevertheless both systems are simple and require no highly sophisticated equipment for their operation. The two systems are described in detail in the following sections.

## MULTIPLE SHOOT PRODUCTION

Woody cuttings of cassava sprout 1-3 weeks after being planted in a moist medium. The shoots or sprouts consist of nodal units each of which comprises a node, an internode, an axillary bud and a leaf. The basis of this rapid propagation technique resides in the fact that the upper part of the shoot can be cut and rooted whilst the axillary buds in the basal part of the young shoot sprout and produce new shoots (Wholey, 1974). The new shoots can in turn be cut and rooted and so on. The main limitations to the rapidity of this technique are (1) the process can only be started when woody lignified tissue is available and (2) the new shoot production only continues whilst

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nutrient and carbohydrate reserves exist in the original woody cuttings.

## Installations

Multiple shoot propagation does not require any sophisticated equipment, however, simple specialized propagation chambers and rooting chambers are required. The propagation chambers (Fig.1) are designed to maintain the original cutting in a high humidity environment. The canals in the base are filled with water and the plastic covers are placed over the centre of the canals. The design of the propagation chambers and the construction materials can be varied according to the availability of local materials.

The rooting chamber (Fig. 2) consists of a work table with a plastic canopy with flaps that can be opened or shut to give access to the work table. The surface of the table should be white and we have also found that the roof height should be approximately 1.5 m above the work table (to reduce the temperature in the chamber). As in the case of the propagation chamber locally available materials can be chosen and used for construction.

## Method

The soil should have good drainage and be reasonably fertile. The soil in the chambers should be sterilized either by sprying it with ten litres of 10% formol using a watering can or instead by adding 1.5 lbs (680 g) of methyl bromide to each chamber. The soil should be covered for five days with a plastic sheet and then left uncovered for a further five days before planting.

A healthy mature plant is required to produce the mother cutting used in this propagation system. Woody parts of the stem are cut into two node cuttings using a hacksaw held firmly in a vice. The stems are cut by rubbing them along the hacksaw blade, which should be cleaned and disinfected with 1% hypochlorite after, approximately, each 20 cuttings are made. The two node cuttings are then immersed in a fungicidal and insecticidal mix (eg. 0.3% Manzate + 1% Malathion for 5 minutes), and following this are planted in lines in the propagation chamber where they are covered with soil to a depth of about 1 cm. When planting the cuttings it is important to see that the shortest distance between two leaf scars is in the apex position (the phyllotaxy of cassava is such that leaf scars are not opposite each other).

166
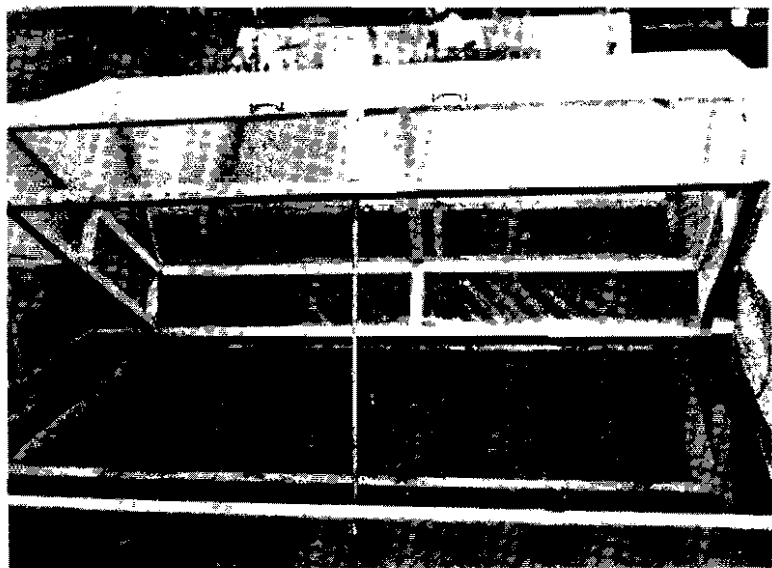
FIGURE 1. PROPAGATION CHAMBER
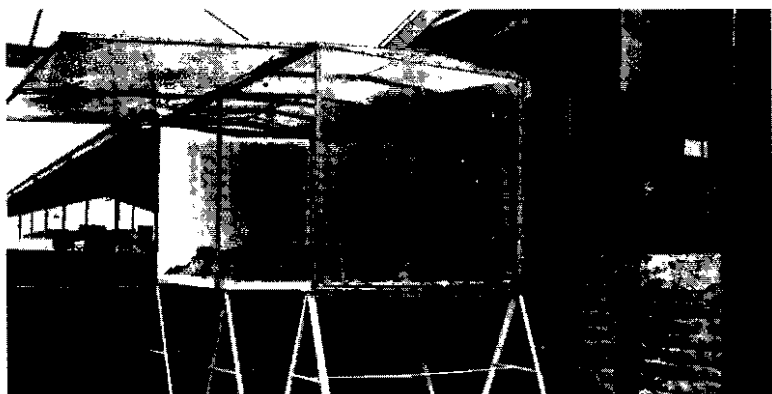


FIGURE 2. ROOTING CHAMBER

167

Once the cuttings have been planted the soil should be watered to field capacity and the plastic cover placed on the chamber. Depending on ambient temperature, shoots will emerge from between 1-3 weeks after planting the two node cuttings. When the new shoots reach a height of 5-10 cms they are cut one centimeter above soil level with a razor blade or sharp knife that has been disinfected in 1% hypochlorite. The shoot is then cut again immediately below the lowest axillary bud and all, except the 2 or 3 uppermost, leaves are cut off. Immediately after this is placed in a beaker containing cold boiled water. This step washes off the latex that exudes from the cut surface and is extremely important for the success of the system.

The shoots are then transferred to 500 ml beakers or similar containers (up to 80 shoots per container) and placed in the rooting chambers. If temperatures are very high or solar radiation intense the propagation chamber should be partially shaded (eg. 50% reduction in incoming radiation). After approximately one week callus forms on the basal cut and roots begin to form. When these roots are still less than 1 cm long (about 2 weeks after placing in the rooting chambers) the shoots should be directly transplanted into the field (Fig.3). If transplanting is delayed until the roots are longer, they will be damaged and the success rate drops markedly. The rooted shoots should be planted deep so that the soil level is just below the lowest leaves. For the first three weeks after transplanting it is essential to maintain the soil near field capacity.

AXILLARY BUD PROPAGATION

In traditional cassava propagation systems the cycles are of 8 months or more as the propagules have to become lignified and this only occurs as plants mature. The axillary bud system however, permits green unlignified material to be used as propagules, thus greatly shortening the propagation cycle, while in addition allowing almost all the axillary buds to be used, not just those on the lignified part of the stem.

Installations

Axillary bud propagation requires a rooting chamber that is a little more sophisticated than that used for the multiple shoot system. The most important aspect of the chamber is the misting system. In a 2 m x 1 m area chamber two misters with a 50 l/hr or less capacity are adequate. The design of the rest of the chamber can be seen in Fig. 4. Twenty centimeters above the bench surface wires are strung at 5 cm intervals to support the leaves and buds.

FIGURE 3.   PLANTLET READY FOR TRANSPLANTING IN THE FIELD.
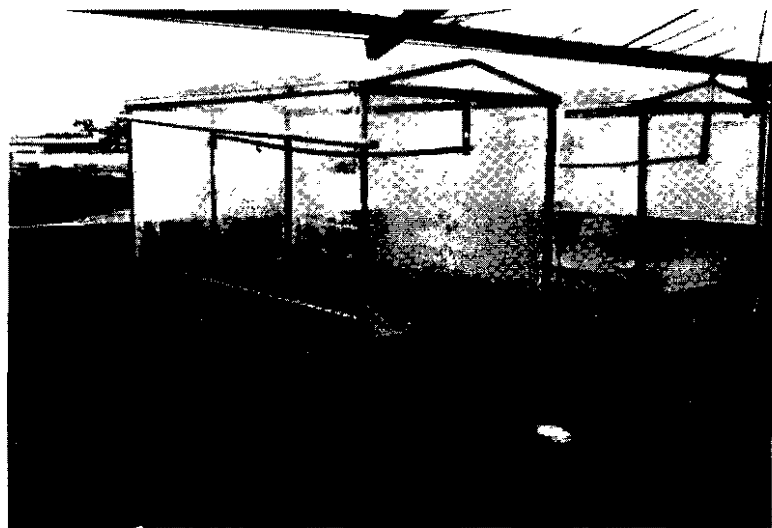


FIGURE 4.   ROOTING CHAMBER

## Method

The small trays are filled with coarse sand or gravel that has previously been sterilized. Healthy mother plants 3 to 4 months old are selected in the field. With a sharp sterilized knife each leaf with the accompaying axillary bud and a small heel of stem tissue is cut from the plant of form the propagules. The leaf lobes are then cut so that the leaf forms a rosette (Fig. 5). The propagules are immediately placed in water, to wash the latex off the cut surface of the heel, and the are placed in the propagation chambers. Small furrows are made in the gravel or sand and the heel is placed in these furrows. It is unnecessary to burry the axillary buds, rather they should be left uncovered. The mist is left running permanently. After one to two weeks small roots are formed on the cut surface of the heel and the petiole abscises. When the shoots present an appearance similar to that in Fig.6. They are ready for transplanting. They can be transplanted directly in to the field, however we have obtained better results transplanting first into peat pots or plastic bags filled with a well drained soil for about one week before field transplanting. Within 3-4 months after transplanting in the field new mother plants are available to repeat the process.

## DISCUSSION

The two methods described greatly increase propagation rates. In the multiple shoot method, starting from a mature mother plant it is possible to produce 12-24,000 commercial stakes in one year, as compared with 100-400 using traditional methods. The axillary bud method is even more rapid producing 100-300,000 commercial cuttings from a 3-4 month old mother plant.

The system described here have beeb ysed successfully under the conditions of Palmira. Modifications may be necessary under different conditions. For example, when average temperatures are less than 20°C rooting will be much delayed and when average temperatures are less than 20°C rooting will be much delayed and when average temperatures are above about 25 °C it may be necessary to shade the propagation and rooting chambers.

Lámina foliar

Pecíolo y yema axilar

Tejido nodal
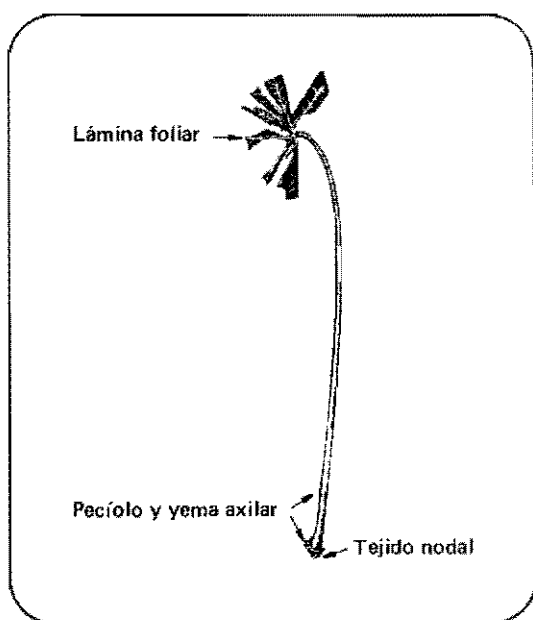
FIGURE 5.   PROPAGATE READY FOR PLACEMENT IN ROOTING CHAMBER



FIGURE 6.   PLANTLET READY FOR TRANSPLANTING

171

# CASSAVA TISSUE CULTURE

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R. Reyes
G. Mafla
J. Roa

## INTRODUCTION

Propagation by stem cutting is the conventional means of planting cassava. This mode of propagation often exposes the crop to a wide range of pests and diseases, especially diseases caused by systemic organisms which can be transmitted with the stakes through successive generations. For instance, cassava bacterial blight, African mosaic disease, superelongation disease, superelongation disease, and frogskin disease can potentially produce up to 100% yield losses (Lozano and Booth, 1974). Thus the propagation not only may affect the productivity of a variety in a locality, but also becomes an important constraint for the maintenance of germplasm collections and for the regional and internationa movement of cassava clones.

It is therefore justified that most of the cassava tissue culture work has been oriented toward the recovery of healthy clones from diseased varieties by meristem and shoot tip culture methods. More recently, however, cell, protoplast, and another culture techniques have been investigated in cassava (Table 1).

## MERISTEM AND SHOOT TIP CULTURE

### General Responses

It was not until the last decade that meristem culture me-

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TABLE 1. SUMMARY OF CASSAVA TISSUE CULTURE RESEARCH

| Explant | Objective[a] | Results | References |
|---|---|---|---|
| Shoot tip | Mass multiplication | Up to three plants | Berbee, 1973; Shillito, Bartha & Gamborg, 1975 |
| Meristem tip | Plant regeneration | Several plants | Kartha, 1975 |
| Meristem tip | CMD eradication | Over 90 symptom-free plants | Kartha & Gamborg, 1975 |
| Meristem tips | Cryopreservation | Tissue survival, 20%, plant regeneration 13 | Bajaj, 1977 |
| Root tips | Rooting generation | 40-50 plants | Roy & Brzozowski, 1978 |
| Shoot tips | Hydrostatic extract | Phytotoxicity | Kartha & Gamborg, 1978 |
| Meristem tips | CMD and CBSD eradication | 30-40% symptom-free plants | Kassel & Fourds, 1979 |
| Meristem tips, internode sections | Hormonal effects | Best cytokinin BA, callus and roots only | Nair, 1979 |
| Shoot tips, single-node cuttings | Propagation, leaf tissue | Multiple shoots, 85 mv tom-free plants | CIAT, 1979 |
| Root tips | Genotype effects, germplasm maintenance | Wide genotype technique, conserved technique | CIAT, 1980 |
| Meristem tips | CMD eradication | Up to 100 symptom-free plants | Adejare & Coutts, 1981 |
| Meristem tips, single-node cultures | Virus disease and CBB eradication, germplasm exchange | Up to 100 symptom-free plants, international exchange techniques | CIAT, 1982a |
| Meristem tips | Cryopreservation | Tissue survival 90%, plant regeneration up to 14% | Kartha, 1982 |
| Stem sections | Callus growth | Callus growth, only rooting | Eskes, 1974 |
| Storage root sections | Callus growth | Callus growth, only rooting | Prabhudesai & Narayanaswamy, 1975 |
| Stem, petioles, leaf sections | Callus growth, C and N sources | Callus growth, C and N sources established, callus greening, only rooting | Parke, 1978 |
| Stem sections | Plant regeneration | Occasional leaf and shoot formation | Tilquin, 1979 |
| Stem, petioles, leaf sections | Callus growth | Callus growth, only rooting | Rey, 1980 |
| Seed cotyledons | Embryogenesis | Somatic embryos, whole plants | Stamp & Henshaw, 1982 |
| Anthers | Organogenesis, haploid induction | Callus growth, only rooting, no haploidy | Liu & Chen, 1978 |
| Anthers | Organogenesis, haploid induction | Callus growth, only rooting, some haploids | CIAT, 1982 |
| Mesophyll protoplasts | Protoplast isolation, organogenesis | Colony formation, occasional shoot | Shahin & Shepard, 1980 |

a Abbreviations in this column are as follows:
CMD - Cassava mosaic disease
CBSD - Cassava brown streak disease
CBB - Cassava bacterial blight

174

ristem culture methods were used with cassava (see Kartha, 1981). The technique, as first established for a new cassava cultivars, employed the MS medium (Murashige and Skoog, 1962), containing vitamins as in the B5 medium (Gamborg et al, 1968), supplemented with NAA, BA, and GA at 1.0, 0.5, and 0.1 µM, respectively (Kartha et al, 1974). Later it was found that BA, amongst several cytokins, was best suited for plant regeneration in the presence of NAA and GA, and that GA has a stimulating effect on shoot growth from meristem cultures (Nair et al, 1979).

In fact, cassava apical meristems can be kept alive for only a short time in MS medium. The use of up to 0.5 µM BA promotes shoot initiation and growth. Further increase of BA concentration retards shoot growth, inhibits rooting, and stimulates callus formation. Addition of NAA to this medium further enhances callus growth and rooting in some varieties. On the other hand, the addition of GA to the BA enriched medium may cause tissue deterioration (Roca, unpublished). It was also found that sucrose interacts with BA in meristem culture of cassava (CIAT, 1980a). At low BA concentrations, shoot elongation is practically doubled when sucrose is increased from 0.03-0.06 M. However, shoot elongation is almost negligible at higher sucrose concentrations, being retarded or inhibited at 0.12-0.15 M sucrose. On the other hand, increasing sucrose from 0.03-0.08 M at low BA concentrations, an increase in sucrose concentration hardly overcomes the inhibition of rooting due to BA, though callus formation increases. Further increase in sucrose concentration causes root browning and tissue deterioration probably as a consequence of osmotic stress.

The incubation of cultures at 22-25 C counteracts the inhibition of rooting caused by BA. Thus high sucrose concentration on the one hand, and low temperatures on the other, tend to produce similar effects on established shoot tip cultures. While root formation is anthocyanic pigmentation are elicited (Roca, unpublished).

Recent findings on the effect of major elements indicate that low total nitrogen concentration (20-40 mM) promotes the growth of roots in length and girth at the expense of shoot growth (Roca and Reyes, unpublished).

BASIC PROTOCOL FOR MERISTEM AND SHOOT TIP CULTURE

Plant Material

1. Cut stakes 10-15 cm long with several dormant buds. preferably obtain the stakes from the middle of the plant.

2. Disinfest the stakes by submersion in fungicide-insecticide mix; then let the stakes dry for a couple of hours.

3. Seal the upper ends of the stakes with melted paraffin.

4. Plant the stakes in pots containing sterilized soil, and place them in a greenhouse or growth chamber at a temperature of 25-30 °C. At this stage, the potted stakes can be subjected to thermotherapy, if needed.

5. Irrigate the pots with Hoagland's nutrient solution at one-third strength or with a soluble fertilizer.


Preparation of Sterile Tissue

1. After about 2 weeks, the sprouts will have grown sufficiently to remove the terminal bud together with a short stem section from each. Rapidly growing vegetative but not flowering buds are most suitable as meristem donors. Collect the buds in a bag or beaker with moist paper towel, but do not place them in water. The outer appendages of the bud may carry contaminants; therefore, preventive disinfestation may be needed.

2. Disinfest the buds by rinsing them quickly in 70% ethanol, then soaking them 2-3 min in a 0.5% solution of sodium or calcium hypochlorite. Wash the buds under sterile conditions three to four times with distilled water. Finally, leave the buds in sterilized water.


Dissection of Buds and Explant Isolation

Basic tools needed include a stereo-microscope (10x-50x magnification) with incident illumination, two No.11 scalpels, two pairs of tweezers, and two microscalpels made with 5-mm pieces of razor blades cemented to a wooden handle. Dissecting needles, 3-5 mm long, made from No.25 hypodermic needles are also needed. The stereo-microscope should be equipped with zoon-type lenses and care should be taken to prevent overheating the tissues with the illuminator. Sterility can be maintained by the use of a laminar flow hood.

The dissecting tools must be sterilized, preferably in the autoclave, prior to use. However, they may become contaminated during work. It is convenient to work with several sets of the same tools, maintaining the asepsis by immersing them in 70% alcohol and then quickly flaming them. Excessive flaming causes loss of temper and oxidizes the metal; furthermore, the accumulation of burned organic material is difficult to remove.

176

1. With a pair of tweesers, support a disinfected but with one hand on the microscope stage. Routinely clean the stage with 70% ethanol and allow it to dry by evaporation. At a 10x-15x magnification, remove the external appendages (leaves and stipules) of the bud using one scalpel.

2. When the internal structures of the bud have been reached, these appear as pale green and three to four leaf primordia remain. At this stage, the shoot tip is 0.8-1.5 mm long and can be cut easily along its morphological neck. The isolated tips adheres to the knife and can be transferred onto the culture medium.

3. The following steps must be done as quickly as possible, otherwise the succulent structures of the meristem dehydrate. Continue dissecting the leaf primordia inward until, at a magnification of about 40x, the youngest primordia can be seen partially encroaching the meristem tip.

4. Remove the young primordia using one curved needle, taking care not to damage the meristem, and cut away the remains of leaf bases as well as other adjacent tissue.

5. All that remains is the dome-shaped apical meristem accompanied by one or two of the youngest primordia. The meristem tip measures 0.4-0.6 mm (Fig.2a).

6. Slant the tip so it can be seen in profile and, using one microscalpel, make the final cut perpendicular to the vertical axis. An alternative to this would be to maintain the vertical tip and make oblique cuts into the opposite sides of the meristem so that they cross in the center.

7. The meristem tip should attack to the point of the microscalpel and be brought to the test tuve and transferred onto the surface of the medium. It is desirable to place the meristem vertically on the agar.

## Incubation of Cultures

Single temperature and light conditions have been used successfully for the incubation of cassava meristem culture (Kartha *et al*, 1979). However, work (Rodriguez and Roca, unpublished) with a wide range of cassava genotypes has shown the requirements for optimal incubation conditions at four critical stages of meristem development (Fig.1).

Stage I: Initiation

A shoot, 1-2 cm in length, often with a small basal callus and without roots, develops from the explant. Depending on the variety this stage may last 2-4 weeks.

Stage II: Rooting

The tip of the shoot, as formed at I, is removed and plant-
ed on a rooting medium. If further growth of the shoot is allow-
ed at Stage I, two to three single nodes can be cut from every
shoot and each of these also rooted (Fig. 1). The approximate
timing for this stage is 1 week.

Stage III: Further Growth

After root initiation has begun and the first leaf has un-
folded, growth of roots and shoots occurs until a complete plant-
let, 4-6 cm in legth, is formed. Larte test tubes allow faster
and larger final growth than small tubes.

Stage IV: Hardening

For successful potting, the cultures require a conditioning
treatment of about 1 week.


Conditions

Temperature: 27-28 °C for Stages I, II and III; 24-25°C
for Stage IV.

Illumination: not higher than 2000 lux for Stages I and II;
4000-5000 lux for Stage III; 8000-10.000 lux for Stage IV.

Photoperiod: maintained at 14-16 hr. throughout.

Light quality: day-light fluorescent lamps throughout


Culture Media

Stage I: MS medium with 1.0 µM thiamine-HCl, 0.6 mM m-inos-
tiol, and 0.058 M sucrose. NAA (0.12-0.2 µM), BA (0.05-0.1 µM),
and GA (0.1 µM) are used as growth regulators. The medium is
solidified with 0.6% Difco agar.

Stage II, III and IV: MS (one-third strength) with 3.0 µM
thiamine-HCl, 0.6 mM m-inositol, and 0.058 M sucrose. The only
growth hormone added to this medium is 0.05-0.1 µM NAA. Agar,
0.8%.


Potting

The hardening period affords the culture a chance to tole-
rate water stress and to quickly adapt to the environment after
potting.
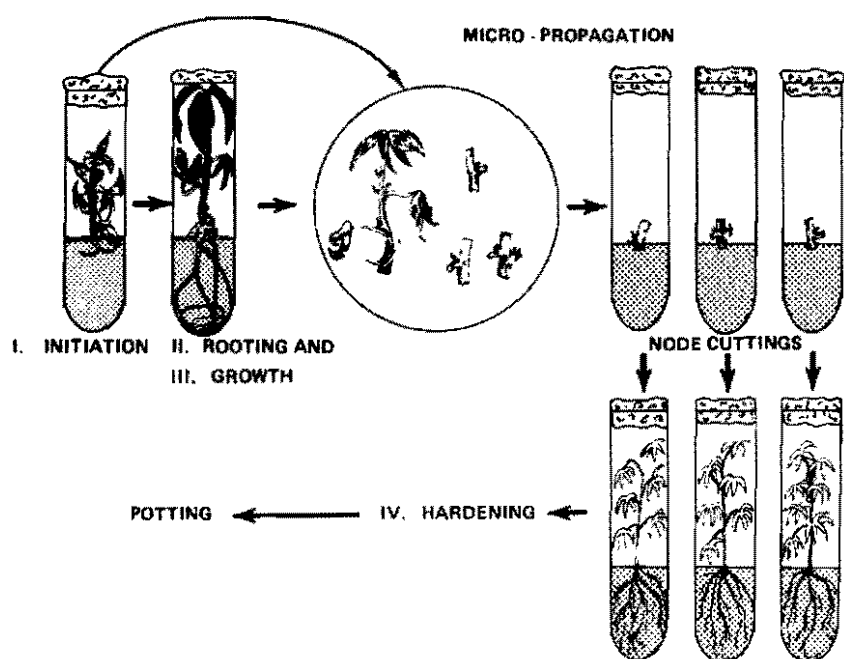
FIGURE 1. TECHNIQUE FOR GROWING WHOLE PLANTS FROM CASSAVA MERISTEMS.
REGARDLESS OF ROOTING, A MERISTEM GIVES RISE TO A SMALL
SHOOT (STAGE I); ROOTING IS INDUCED ON APICAL (STAGE II)
AND SINGLE-NODE CUTTINGS (STAGE III). AFTER A HARDENING
TREATMENT (STAGE IV), PLANTLETS ARE POTTED. MEDIA COMPO-
SITION AND CULTURAL CONDITIONS ARE DESCRIBED IN THE TEXT.

1. Move the test tubes containing the cultures to a clean
bench in the greenhouse.

2. Use substrate comprised of one part soil and three parts
fine sand, properly sterilized. "Jiffy" type, plastic or clay
pots can be utilized.

3. Uncap the tubes and remove the plantlets with the aid
of forceps. Holding the plant with one hand, wash the roots

179
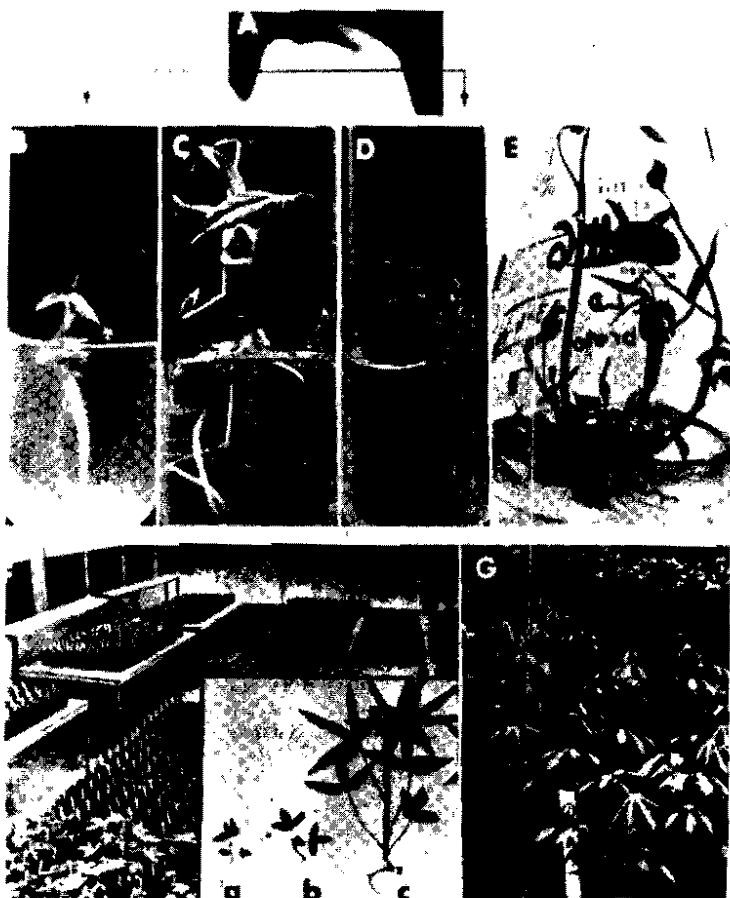
FIGURE 2.   PROPAGATION OF CASSAVA BY MEANS OF MERISTEM CULTURE.  A
MERISTEM TIP (A) NORMALLY GROWN INTO A SINGLE PLANTLET (B
AND C), BUT CAN BE INDUCED TO FORM ROSETTE CULTURES (D)
WHOLE AXILLARY BUDS GROW INTO MULTIPLE SHOOTS (E) IN LIQUID
ROTATED MEDIUM.  APICAL AND SINGLENODE CUTTINGS FROM MULTI-
PLE SHOOTS ARE ROOTED TO FORM WHOLE PLANTS FOR POTTING (F).
WATERING WITH A FERTILIZER RICH IN PHOSPHORUS (c), COMPARED
TO TAP WATER (a) AND HOAGLAND'S SOLUTION (b), ENHANCES VI-
GOROUS GROWTH FOR SUCCESSFUL FIELD ESTABLISHMENT (G).

thoroughly with clean running water.

4. Place the roots, plus one-third of the shoot, in a hole made in the center of the substrate. Then firm the substrate around the plant.

5. Immediately water the pots. The use of a soluble fertilizer rich in phosphorous greatly enhances the growth of the plantlets (CIAT, 1982c). A fertilizer with formula N-P-K (10-52-10) produced a 50 to 100-fold increase in fresh weight within 1 month, compared to watering with Hoagland's nutrient solution or tap water, respectively (Fig. 2f, inset).

6. Place the pots under high relative humidity. This is achieved by placing the ports on trays containing sterilized dampened soil and covering them with a plastic hood. The chamber must be kept away from the sun and strong winds (Fig. 2f). Conditions inside the potting chamber should be 30-40 °C during the day and 18-25 °C at night, with illumination around 20,000 lux, and relative humidity near saturation during the day and 70-80% at night. One chamber of 1 x 2 m in size can hold up to 200 "jiffy" type pots.

7. One week after potting, open the lid of the chamber gradually until the plants are completely exposed to the greenhouse environment. Continue watering with high phosphorus until the fourth week.

Transplanting to the Field

1. Plants 10-15 cm tall and comprised of 8-10 leaves are appropriate for transplanting to the field.

2. Choose a cloudy day. Otherwise, make the transplant late in the afternoon. The soil moisture should be at field capacity. Do not move the pots from the trays; carry them together to the field.

3. Remove all the large leaves from the plants, and place each one in a hole large enough to cover up to the middle of the shoot. Press the soil around the plant. If "jiffy" pots or plastic bags have been used for potting, there is no need to expose the roots completely; it is only necessary to remove the bottom of each pot to allow faster establishment.

4. Up to about 1 month from transplanting, maintain high soil humidity and watch for possible insect damage. At this point, meristem-derived plants can be treated conventionally (Fig. 2g).

## Effect of Cassava Genotype on Meristem Culture

The successful regeneration of plants from meristem culture depends on the interaction of the genotype with the culture medium and with the physical conditions of culture. Thus, it can be expected that different cassava varieties would react differently to meristem culturing.

Work conducted with over 300 cassava cultivars from Latin America indicated a general tendency among varieties to form shoots more readily than shoots and roots in the same medium. This tendency was related to increasing concentrations of BA. Attempts to overcome the lack of rooting with higher NAA level resulted in callus proliferation.

A two-step technique was devised for the generation of whole plants from a wide range of cassava genotypes (CIATm 1980a). In the first step, meristem tips are cultured in a medium designed to enhance shoot formation regardless of rooting; in the second step, apical segments are removed from each shoot and planted on a rooting medium (Fig. 1). Media composition for steps one and two are those described earlier for Stages I and II, respectively. This technique not only allows quick rooting irrespective of the variety, but also avoids or diminishes callus formation at the shoot-root transition zone, a desirable condition for successful potting.

## Multiple Shoot Cultures

Previous work with cassava shoot tip culture (Table 3) failed to exploit the potential of the technique for rapid propagation.

The apical dominance, evident in the uppermost four to six primordial nodes of a cassava vegetative shoot apex, can be overcome by altering the composition of the culture medium (CIAT, 1979). Meristem tips cultured in MS medium with 0.05 µM NAA and increasing concentrations of BA, gradually developed into shortenend shoots comprising many nodes; the number of nodes increased in proportion to BA concentrations of 2.5-5.0 µM, and then decreased above 5.0 µM BA. Conversely, shoot elongation gradually decreased with BA concentration (Fig.3). At optimal BA concentrations, rosette cultures were formed which were comprised of 10-20 nodes each, depending on the variety (Fig. 2). Microscopic observations of the rosettes showed incipient growth of the axillary but at each node. However, further growth of axillary buds occurred preferentially when the concentration of BA was reduced to 0.25 µM in the presence of 0.1 µM GA and 0.1 µM NAA in rotated liquid MS medium. Compared to the well-known single shoot culture (Figs, 2b and c), the growth of axillary

182
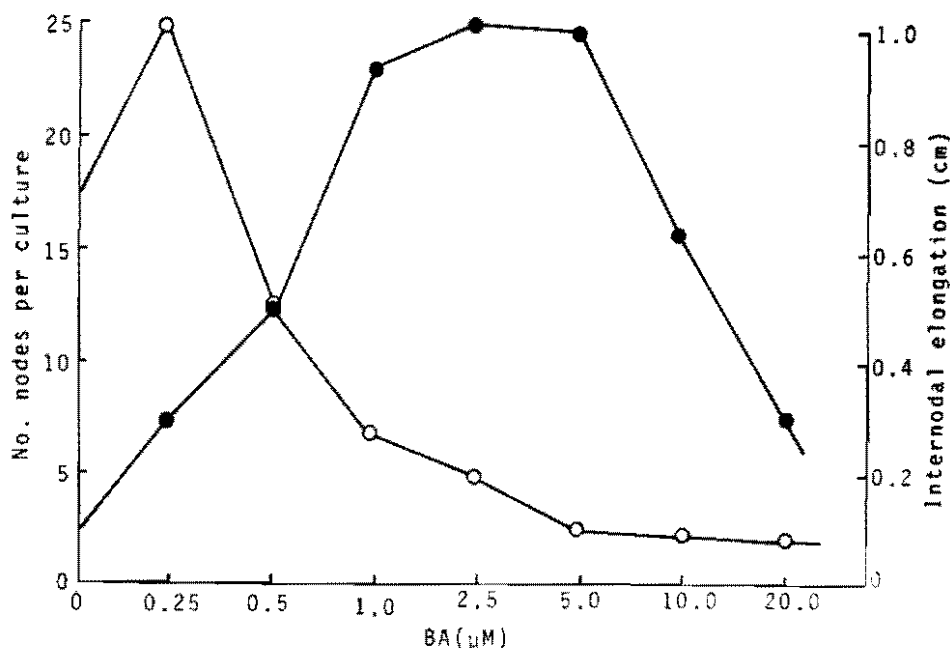
FIGURE 3. EFFECT OF BA CONCENTRATION ON THE NUMBER OF NODES (DOTS) AND
THE ELONGATION OF INTERNODES (CIRCLES) OF ROSETTE CULTURES
DEVELOPED FROM CASSAVA MERISTEMS. DATA REPRESENT THE AVER-
AGE OF FOUR CULTURES. FOR OTHER CULTURAL CONDITIONS, SEE
TEXT.

buds on rosette cultures gave rise to multiple shoot cultures
(Fig. 2e). Apical and single node cuttings were "harvested"
at weekly intervals and transferred to a rooting medium for
recovery of plantlets (Fig. 1). Up to 20 apical and nodal cut-
tings could be harvested weekly from each multiple shoot cul-
ture; however, the rate of shoot formation declined with time
(Fig. 4).

Rapid in vitro propagation techniques could be used pro-
fitably within schemes on maintenance and international exchan-
ge of cassava germplasm in which in vitro propagation would be
used to produce healthy planting material.

APPLICATIONS OF MERISTEM CULTURE METHODS TO CASSAVA

Production of Healthy Clones

Despite the paucity of knowledge on the etiology and accu-
rate diagnosis of cassava viral diseases, previous work has de-
monstrated that healthy (symptom-free) cassava plants can be
produced by a proper combination of thermotherapy and meristem
183

apical meristem seems applicable to cassava (see Kartha, 1981).
The number of plants free of the African mosaic disease was
very small when the meristem explant exceeded 0.4 mm in size;
however, when heat therapy was applied to the infected stakes,
nearly 100% symptom-free plants were produced even with meri-
stem explants measuring up to 0.8 mm (Kartha and Gamborg, 1975).
Work on the eradication of a mosaic disease from the Caribbean
(CIAT, 1979) and frogskin disease (CIAT, 1982b) resulted in 85%
and nearly 100% symptom-free plants, respectively.  The culture
of small meristem explants, after heat therapy of infected sta-
kes, was essential.  The frogskin symptom-free plants have been
vegetatively propagated through consecutive cycles with the re-
sult that such condition still remains.

Ribavirin, a chemotherapeutic compound with broad antiviral
activity against both DNA and RNA containing viruses (Lerch,
1977), has been used experimentally for controlling frogskin
disease.  Preliminary results showed high phytotoxicity when
applied to sand-grown sprouts but not when it was applied to
shoot tips in vitro (Roca and Roa, unpublished data).

Recovery of Varietal Yield and Vigor

A gradual decline or degeneration in yield and vigor of
local cultivars may result from the accumulation of diseases
that may become manifested through symptoms or remain latent.

Root yield increases have been obtained at CIAT due to
cleaning cassava cultivars infected with viral-like pathogens.
In the last 6 years, nearly 800 cassava cultivars have been pro-
cessed through thermotherapy-meristem culture and handed to the
breeders and agronomists for use in performance trials under
various agroclimatic systems, along with local "uncleaned" cul-
tivars and new breeding lines.

Yield s of Secundina, a popular variety from the Colombian
north coast, have been diminished due to a viral disease named
Caribbean cassava mosaic (CCM) (CIAT, 1982b).  The symptoms of-
ten pass unnoticed in the farmer's field. but show up through
grafting or under greenhouse conditions.  Clean material has
been produced through thermotherapy followed by meristem culture,
the propagated and sent back to the north coast for in-farm
trials.  Root yield increases of 70% in fresh weight and starch
content were obtained in comparison to the use of traditional
planting material of Secundina; no differences in yield were
found between the meristem culture-derived Secundina plants and
a breeder's hybrid (CM 342-170) selected for the same region
(Lozano *et al*, 1983).

The cassava cultivar Llanera was quite preferred by farmers
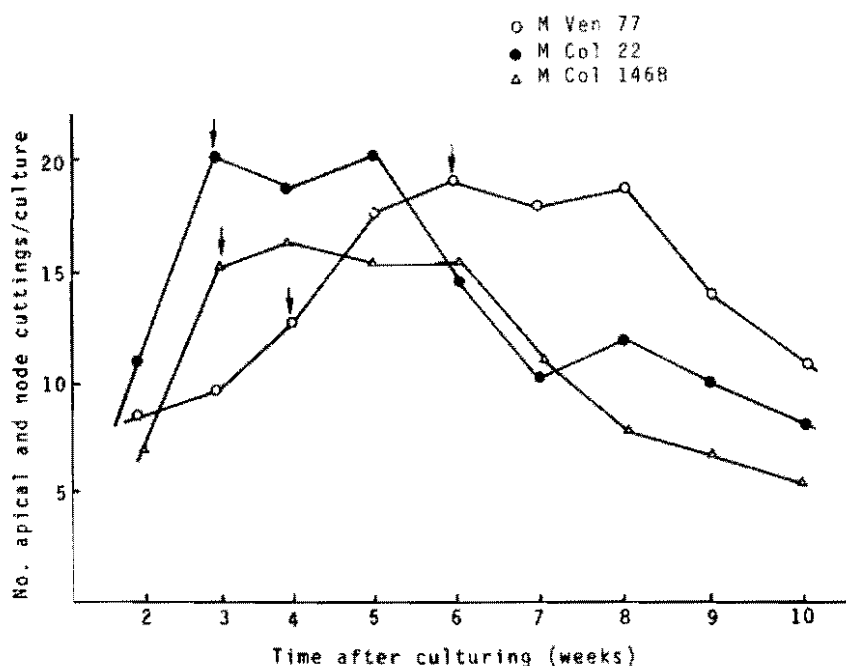
FIGURE 4. IN VITRO PROPAGATION OF CASSAVA THROUGH MULTIPLE SHOOT
CULTURES. PRODUCTION OF APICAL AND SINGLE-NODE CUTTINGS
"HARVESTED" FROM MULTIPLE SHOOT CULTURES OF THREE VARIE-
TIES IN LIQUID ROTATED MEDIUM. ARROWS INDICATE REPLENISH-
ING OF FRESH MEDIUM. SEE THE TEXT FOR CULTURAL CONDITIONS.

culture (Table 3). Although mechanical transmission of the
brown streak disease and the African mosaic disease has been
reported (see Kaiser and Teemba, 1979; Adejare and Coutts, 1981)
the exact etiological agents have not conclusively been identi-
fied. A similar situation currently exists for the frogskin
disease and other mosaic diseases of possible viral etiology
(CIAT, 1982b). Certain indexing techniques such as sap inocula-
tion on indicator plants, grafting of resistant material onto
sensitive varieties, and visual evaluation of symptoms provide
relative diagnostic criteria. However, the meristem culture-
derived plants can only be considered symptom-free until more
sensitive indexing methods become available. Recent results
have demonstrated the presence of electrophoretic unique pro-
teins associated with a viral disease known as frogskin (CIAT,
1982). In addition, detection of a mosaic disease and of use
so called Caribbean cassava disease have been possible through
serological and grafting tests, respectively.

The number of disease-free plants produced by meristem
culture depends on the virus, the variety, and the proper use
of the technique. The general principle that the relative
number of virus particles decreases acropetally toward the

until a few years ago when it gradually began to diminish its yield in the Colombian Cauca Valley. The growth of meristem culture-derived plants has not only increased general vigor, but fresh root yield is 30-40% as compared to conventional plantations (Roca and Coral, unpublished results). Graft-indexing seems to suggest the existence of a latent viral type disease in the farmers' stocks (Javashinghe, pers. comm.).

Recently another cassava virus-like disease called frog-skin has been shown to reduce yields drastically in many cultivars. Thermotherapy, followed by meristem culture, has been very effective in producing healthy stocks and recovering yield and vigor. Nearly 500 varieties from the germplasm collection of CIAT have been cleaned from the frogskin disease (Roca and Roa, unpublished results) in the last 5 years.

These examples show that farmers' crop yields can be sustantially increased through simple meristem culture methods. This approach can be especially useful in the case of traditional cultivars in the poor regions of developing countries, where short-term solutions to agricultural problems are needed, since the development of new varieties through breeding is a time-consuming task.

## PROTOCOL FOR THE PRODUCTION OF HEALTHY CLONES

The overal meristem culture-mediated control of cassava diseases entails: (a) etiology of the disease, (b) application of thermotherapy followed by meristem culture, (c) indexing for freedom of pathogens, and (d) propagation of healthy clones under conditions to minimize reinfection. Steps (a) and (c) are beyond the scope of this chapter.

1. Prepare the plant material as indicated in the basic meristem culture protocol.

2. Place potted stakes in a growth chamber at 35°C, with 6000 lux illumination and a 14-hr photoperiod for about 1 week.

3. Gradually increase the day temperature (1°C per day) up to 40°C; maintain the night temperature at 35°C.

4. After 3 weeks of thermotherapy (40°C during the day and 35°C at night), remove the apical bud from every sprout and proceed to surface-sterilize.

5. Meristem isolation and culture, as well as potting, etc., should be conducted as specified in the basic protocol.

6. Carry out indexing with available techniques. If possi-

ble, indexing could begin at the test tube level prior to potting, then confirmed with potted plants.

7. Keep healthy plants under conditions that prevent or minimize recontamination, especially if the disease is transmitted by insect vectors or is highly transmissible through mechanical means, soil, or water.

8. Propagation of healthy plants follows. In vitro propagation is the most secure method to practically eliminate recontamination of healthy materials by means of insects, soil, water and even through the air.

As shown before, cassava can be multiplied in vitro by a combination of multiple-shoot culture (Fig. 2d and e) and single node cuttings (Fig.1). In practice, this propagation can provide enough basic material for use in more conventional rapid multiplication. Conventional propagation of cassava is very slow; only 10-20 stakes can be produced per year per mother plant. Two improved techniques have been adapted. One utilizes sprouts grown on 2-node stakes (Cock *et al*, 1976) and the other utilizes single leaf-bud cuttings obtained directly from the mother plants (Roca *et al*, 1980). The former can potentially yield up to 36,000 stakes and the latter, up to 300,000 stakes per year per mother plant.

## Germplasm Conservation

The potential danger of genetic erosion of both cultivated and wild cassava germplasm resources may be attributed to the replacement of primitive cultivars by new varieties or hybrids and the incorporation of new land to agriculture in the areas of genetic diversity (Hershey, pers. comm.). Such danger, and the requirement of genetic variability for use in the improvement of the crop, justifies cassava germplasm conservation efforts.

Conventional maintenance of cassava germplasm collections is done by continuous vegetative field cultivation. New germplasm plantings often use freshly cut stakes from old fields. Besides the high costs, field maintenance often exposes the valuable germplasm to insect attack, disease infection, and soil or climatic problems. Freshly cut stakes can only be kept for a short time because of premature sprouting and insect or microbial attack. Chemically treated stakes have been maintained for up to 6 months, but vigor of the planting material, as well as yield, decreased (Sales-Andrade and Leihern, 1980). Furthermore, because of their bulkiness, stakes can potentially harbor systemic contaminants. Seeds also can be used to maintain cassava germplasm. Seeds stored at 5°C and 60% relative humidity have maintained their viability for several years (Hahn *et al*, 1973).

FIGURE 5. IN VITRO MAINTENANCE AND INTERNATIONAL EXCHANGE OF CASSAVA
GERMPLASM. AFTER 18-24 MONTHS OF STORAGE AT 20-22°C (A)
CULTURE VIABILITY IS MAINTAINED THROUG AXILLARY BUD (ARROW),
WHILE STORAGE AT 27-28°C (B) DIMINISHES VIABILITY. RETRIEV-
ED CULTURE FROM 20-22°C AFTER 1 YEAR OF STORAGE (C); NOTE
AXILLARY BRANCHING (ARROW). SINGLE ROOTED PLANTLETS (D) AS
PREPARED FOR PACKING AND INTERNATIONAL DISTRIBUTION (E).
POTTED PLANTS UNDER SANITARY CONDITIONS AFTER RECOVERY FROM
INTRODUCTIONS AS IN VITRO CULTURES (F).
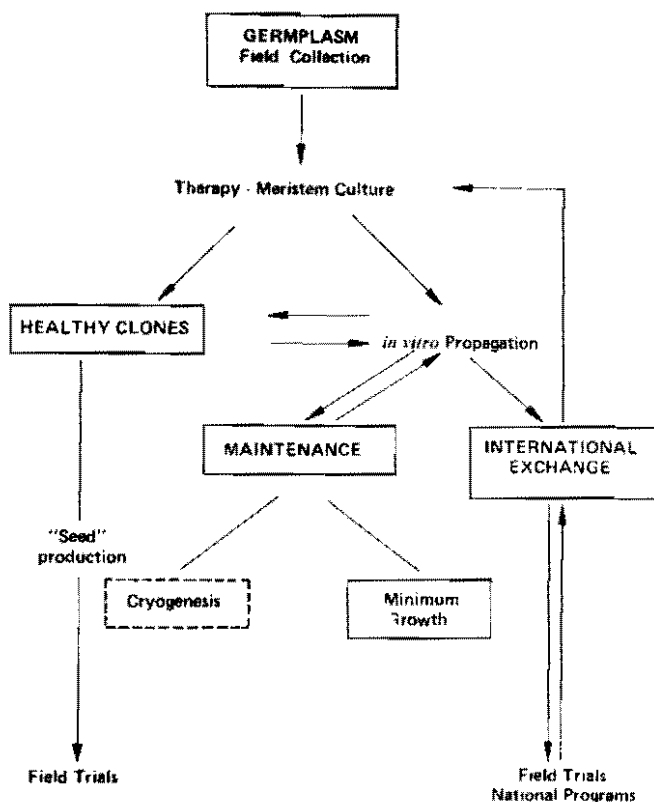
FIGURE 6. FLOW DIAGRAM SHOWING THE UTILIZATION OF CASSAVA MERISTEM
CULTURE FOR THE PRODUCTION OF HEALTH CLONES, AND THE MAIN-
TENANCE (THROUGH MINIMUM GROWTH STORAGE AND CRYOGENESIS)
AND INTERNATIONAL EXCHANGE OF GERMPLASM IN CLONAL FORM.

Although cassava seedlings can be free of most diseases. adapted genotypes can not be preserved by seeds dur to their high genetic segregation. But if sufficient number of seeds can be collected from random crosses, the nonfixed alleles of an accesion could be preserved (IBPGR, 1982).

Meristem culture methods can be used for maintenance of cassava germplasm because of their freedom from microorganisms and their small space requirement, coupled with their potentially high propagation rates and high phenotypic stability.

Maintenance of cassava germplasm by means of meristem culture can be done in combination with cryogenic techniques, or through minimum-growth storage conditions.

Cryogenesis

Prior results from cassava freeze-preservation studies have shown low tissue survival (Henshaw and Stamp, pers. comm.) and low plant regeneration after retrieval of shoot tips from liquid nitrogen (Bajaj, 1977). In addition, it was found that cassava meristems were very sensitive to many cryoprotectants which could arrest or modify organogenesis (Kartha and Gamborg, 1978). Recent findings, however, have demonstrated the feasibility of cryogenesis with cassava. Meristem tips, 0.4 and 0.5 mm in size, were frozen in droplets of MS medium with dimethyl sulfoxide and sucrose as cryoprotectants. A terminal temperature of -25°C, prior to storage in liquid nitrogen, resulted in 90% tissue survival and up to 10% whole plant regeneration (Kartha *et al*, 1982).

Minimum Growth Storage.

Recent research has provided a means to maintain cassava clones in vitro. The storage temperature, illumination, and variations in the composition of the medium (osmotic level, nutrient limitation, growth hormones, and other factors, such as the addition of activated charcoal to the medium and the use of large culture vessels for storage) all had an influence on the rate of growth and viability of single node cultures (CIAT, 1980). Throughout 18-24 months of storage at 20°C, the rate of shoot elongation decreased to about one-fifth that of cultures kept at 25-30°C (Figs. 5a,b). Storage temperatures lower tjam 18°C were detrimental to a number of cassava varieties if the illumination was kept high. However, culture viability could be maintained at even lower temperatures (10-15°C) as long as the illumination was also lowered to less than 500 lux. Increasing BA from 0.044 to 0.22 µM, on the one hand, and sucrose from 0.058 to 0.12 M, on the other, also slowed down shoot elongation, with over 90% viability. However, if low-

temperature storage is combined with high BA and sucrose levels, the growth of cultures is arrested to the degree that most of them become deteriorated after 3 months. Recent findings (Roca *et al*, 1983) indicate that culture growth is decreased when the total nitrogen content of the medium is lowered to 20 mM at 27-28 °C and to 40 mM at 20-22°C, Mannitol at 5-25 mM was found effective in arresting growth, but decreased tissue viability at the lower storage temperature. However, if mannitol is added to the medium, along with 0.088 and 0.18 M sucrose, culture viability significantly increases at both low and high storage temperatures.

More than 2200 cassava varieties from CIAT's germplasm collection have been transformed into in vitro cultures for storage. Depending on the variety, these cultures can be maintained for 18-24 months without transfers to fresh media. Varieties differ in their relative tolerance to the low temperature and in their relative rate of growth. Furthermore, old cultures from certain varieties tend to deteriorate as a consequence of the oxidation of phenolic-type exudates from the roots. Throughout storage, the cultures produce axillary buds (Fig.5c). The number of axillary buds per variety is directly related to culture viability, and hence, to plant regeneration upon retrieval from storage. At the end of each storage cycle, the axillary buds are transferred to a fresh medium in order to initiate a new cycle. The germplasm bank in vitro (a room 5 x 6 x 2 m in size) can potentially hold 5000 cassava accessions that otherwise require over 8 ha of land area.

Sample cultures are retrieved from storage once or twice per year, micropropagated, and grown in the field along with stake-propagated plants. Evaluations of phenotypic stability are under way using morphoagronomic and biochemical criteria, but, in general, the plants look true-to-type. Narrowing of leaf lobes has been observed in a few varieties following retrieval from storage and growth in the field, but reversion to the wider lobe type began after the second vegetative growth cycle (Roca and Coral, unpublished).

International Exchange of Germplasm

Quarantine regulations for cassava vary from country to country, from those which readily allow the introduction of stakes (some Latin American countries) to those that strictly prohibited their entrance (several countries in southeast Asia, Africa and Latin America).

As mentioned above, several cassava diseases are caused by systemic organisms such as virus, bacteria and fungi. These pathogens can be disseminated, often without noticeable signs, within the stakes. Frequent introductions of pathogenic orga-

nisms to a given locality increases the probability of their establishment and prevalence (see Hewitt and Chiarappa, 1977). This can be especially critical if cassava is moved from its center of origin-which may also be a center for diverse pests and diseases-to other areas of the world. On the other hand, certain cassava diseases are geographically confined or their occurrence has not been reported elsewhere. For instance, the transfer of materials from Africa and India to America has been restricted due to the apparent absence of the African mosaic disease in the latter (Lazano, 1977). Similarly, every precaution needs to be taken in moving materials to various southeast Asian countries which seem to remain "clear" of various important viruslike diseases.

A plantlet (derived from meristem culture of hear-treated stakes) maintained in vitro in a sterile nutritive artificial medium should be free of insects, mites, nematodes, fungi, and bacteria (Kahn, 1977). Should the latter be present, it could be detected readily because of media contamination. If a fastidious organism is present, a special media to support its growth would be needed. To test the absence of virus or viruslike organisms, available indexing techniques should be used. Thus, the use of in vitro cultures for the international exchange of cassava germplasm constitutes an additional safeguard for minimizing the risks of pest and disease dissemination.

International exchange of germplasm (CIAT, 1982c) involves the following steps:

1. The establishment of in vitro cultures. Single rooted plantlets (Fig. 5d) are the simplest form of in vitro cassava clones for shipping. The rooted plantlets are derived from apical and single-node cuttings. Except for the use of 1% agar, the cultures are prepared as described in the basic protocol. The materials distributed in vitro from CIAT include selected varieties, basic germplasm, and promising hybrid lines

2. The packing and shipment of cultures. The cultures are packed in polyestyrene boxes (Fig. 5e). Each package is properly labelled to expedite rapid clearance from the customs office to the Plant Health Services and from there to the institution from which the request originated. The proper phytosanitary documents should be included in the package, the list of materials with their protocol on the handling of the cultures at the receiving end. The cultures should be shipped by air, preferably as accompanied luggage; otherwise they can be air freighted or air mailed. Cassava is highly sensitive to protracted darkness. Shipments longer than 2 weeks cause etiolation, chlorosis, and finally tissue deterioration. Such detrimental effects can be partially prevented if short, vigorours, plantlets are prepared for shipment. This is accomplished through the exposure of the cultures prior to shipment to

8000 lux illumination at 24-25°C. Furthermore, the use of 2,4-D in lieu of NAA diminished etiolation, and when 2,4-D was added together with BA, both defoliation and chlorosis due to darkeness were decreased.

3. The handling of cultures at the receiving end is the next part of the process. This is the most critical step in the international exchange of in vitro cassava. Successful handling of cultures after arrival depends on two factors: the time elapsed between shipment and arrival and the physical and personal facilities of the receiver. Actually, the in vitro system is only effective as a tool if managed by well-trained personnel. The overall task is to move the plantlets, after their arrival, from the test tube to the field. Through training and follow-up programs it has been possible to organize a network of collaborating institutes in various Latin American and southeast Asian countries. Fairly good facilities for handling in vitro cultures now exist in Brazil, Mexico, Costa Rica, Cuba, Venezuela, the Phillipines, Thailand, Malaysia, and Indonesia. Several of the collaborating institutes are able to recover plants from the cultures through the in vitro node-cutting technique (Fig. 1) and carry them up to the field for further multiplication and testing. Minimum handling in other countries only involves direct potting of the culture after a period of hardening.

The in vitro culture methodology has been accepted by various countries as one of the safest means of receiving vegetative cassava material. This is recommended method for the transfer of genetic resources both from the collection site to the main germplasm centers and from these to the national programs (IBPGR, 1982).

Between 1979 and 1985. more than 500 cassava materials (varieties and hybrids) were distributed from CIAT to numerous countries in America as in vitro cultures. Similarly, nearly 50 cultures were shipped to southeast Asian countries and 15 clones to other countries.

The in vitro system also has been utilized to introduce to CIAT new cassava germplasm from countries in Latin America. Between 1979 and 1982, nearly 1500 accessions were introduced as meristem cultures. Following in vitro micropropagation, these materials were moved to the greenhouse for phytosanitary observation (Fig. 5f), then to the field for further multiplication and use in germplasm trials.

## Summary

To summarize, meristem and shoot tip culture techniques
have been utilized only in the last decade mainly as a means
for ridding selected cassava varieties of viruses.  More re-
cently, the use of these techniques has been extended to the
maintenance and international exchange of cassava germplasm.
The future of cassava cryogenic storage is promising.  Mini-
mum-growth storage is now a viable method for maintaining
large collections in small spaces free of pests and disease
risks.  International movement of in vitro cassava provides
a valuable safeguard for minimizing the dangers of pest and
disease dissemination.  The various applications of meristem
culture are presented diagramatically in Fig. 6.

## OTHER TISSUE CULTURE METHODS IN CASSAVA

Compared to meristem and shoot tip culture, the develop-
ment of cell, callus, protoplast, and another culture in cas-
sava is still in its infancy.  More extensive work is needed
on this subject.

## Embryo Culture

There have not been any attempts to recover plants from
the culture of immature embryos of cassava.  Past experience
in the interspecific hybridizations of *Manihot* (Nassar, 1980)
shows that there are no substantial barriers to successful hy-
bridization.  Nevertheless, embryo rescue techniques may be-
come a valuable tool in the recovery of certain crosses.

On the other hand, plants have been grown from cultured
embryos dissected from mature seeds of 6 wild cassava species.
Using this technique some plants have been recovered that
otherwise would not have survived because of the very poor ger-
mination of seeds in several *Manihot* species (Rodriguez and
Roca, unpublished).

## Cell and Callus Culture

### Callus Growth

Callus has been induced from stem, petiole, leaf and even
root sections of cassava (Table 3).  In general, stem sections
seem best suited for callus induction.

The main requirements for callus initiation, growth, and

maintenance have been established. The MS medium seems better than WH medium. Sucrose (0.03-0.087 M) is a good carbon source; although the dry weight of callus increases with up to 0.087 M sucrose, the callus turns brown at higher concentrations.

As auxins, 2,4-D and NAA seem better suited than IAA for callus initiation, growth and maintenance. More rapid growth is achieved with a combination of 2.4-D (5.0-13.0 µM) and a cytokinin. With KIN or BA (2.0-8.0 µM), callus growth is rapid, but greening may occur more readily with 2iP or ZEA (10 µM).

Common nitrogen sources such as ammonium nitrate (20 mM) and potassium nitrate (19 mM) support callus growth as well as the combination of ammonium chloride (20 mM) and potassium succinate (10 mM) though the latter may be better for greening. Organic additives such as CW (10-18%) can increase callus growth in the presence of 2,4-D, but browning also has occurred with CW in the medium.


Organogenesis

Root formation in callus cultures is readily obtained with the aforementioned media, especially when NAA is used as the auxin. Addition of BA up to a certain concentration seems to promote rooting, but at higher concentrations all cytokinins counteract the rooting effect of auxins. Thus, for the maintenance of undifferentiated callus, both auxins and cytokinins need to be present.

Tilquin (1979) claimed that leaves and shoots were occasionally regenerated from callus grown from stem sections on the same medium as that used for meristem culture (Kartha and Gamborg, 1975). However, attempts to reproduce those results have been unsuccessful (Rodriguez and Roca, unpublished).


Somatic Embryogenesis

Somatic embryos and whole plant have been regenerated using cotyledonary explants dissected from mature cassava seeds (Stamp and Henshaw, 1982). The highest frequency of embryo formation occurred in MS medium with high 2.4-D (20 µM); development of embryos was enhanced with lower 2,4-D (0.05 µM) and with the addition of BA (0.5 µM). Embryogenesis was always observed to occur from cotyledonary tissue and not from callus tissue. Embryogenesis obtained from genetically segregating tissues, such as the seed cotyledons, may help identify the requirements for somatic embryogenesis in callus of clonal origin in cassava. Presently at CIAT, plants have been regenerated, through somatic cell embryogenesis, using leaf segments of

not be discarded.  Given the fact that all attempts to induce whole plant differentiation have been done with very few genotypes, it would be worthwhile to screen large germplasm collections for regenerative ability in callus culture.  Basic requirements would be determined with the selected genotypes and extended to other materials.

Inbreeding depression may already exert an effect at the cellular level in anther culture; thus genotypes with very low inbreeding depression should be selected for use in the development of the technique.

## FUTURE PROSPECTS

### Meristem and Shoot Tip Culture

Important problems in a vegetatively propagated crop such as cassava are associated with the production of disease-free stocks and germplasm storage.  Meristem culture integrated with disease diagnostic techniques seems a logical approach for initiating the production of disease-free materials in national programs of individual countries.  Large amounts of planting material could then be produced using clean donor stocks.  The problem of varietal decline, due to some king of degeneration and loss of resistance to diseases, may be approached through clean "seed" production.

The development of in vitro germplasm banks will shortly become an important support to conventional field maintenance of large collections and should be a valuable alternative in the conservation of cassava germplasm in the future.  Cryogenic storage will make such an alternative even more attractive.

In vitro work with germplasm banks will expedite the exchange of clonal materials internationally with less risk of pest and disease transfer.

### Cell, Protoplast, and Anther Culture

Cell culture methods should become an important aid to cassava germplasm improvement in the future.  Breeding for characters controlled by recessive genes is difficult in cassava, and even more so if the character is tetrasomically inherited (Bellotti and Kawano, 1980).  For example, no forms devoid of cyanogenic glycosides have been found in cassava or wild *Manihot* species (Jennings, 1976), and the incapability of producing the glycoside seems to be due to recessive genes (Hahn *et al*, 1973).  Thus the homozygosity needed to express acyanogenesis would be difficult to achieve by conventional breeding methods.

10 cassava cultivars.

## Protoplast Culture

Protoplast from leaf mesophyll cells have been isolated successfully and induced to regenerate cell walls and form callus. However, shoot formation was only observed occasionally (Bidney, pers. comm.; Shahin and Shepard, 1980).

Protoplast can be isolated from plants grown in growth chambers, from shoot tip cultures, or from cell suspensions (Rodriguez and Roca, unpublished). Macerozyme and cellulase or macerase and driselase have been used for enzymatic digestion of cell walls. Colony formation and callus growth were induced following a series of passages on various media (Shahin and Shepard, 1980).

Based on these investigation, a procedure has been standardized at CIAT (L.Szabados, pers. comm.) to isolate, and culture mesophyll protoplastos of cassava.

## Anther Culture

Callus and root formation, but not shoot formation, were reported for anthers cultured in MS medium supplemented with BA and NAA (Liu and Chen, 1978). Green areas developed on callus with the addition of either GA or ABA. Activated charcoal arrested growth; however, cold pretreatment of anthers enhanced callusing. Examinations of preparations of squashed, stained callus cells indicated that the callus originated from somatic tissue.

In recent work with cassava anther culture (CIAT, 1982c), floral buds of 1.5-2.5 mm, corresponding to late tetrad through late uninucleate microspore, were utilized. Callus and then roots formed in MS medium supplemented with BA, NAA and CW. Chromosome counts indicated haploidy in a few root tips. In some varieties nearly 100% of the anthers formed callus, while in others callus formation was variable both between plants and even within anthers of the same plant.

## Conclusion

It can be concluded that the inability to regenerate whole plants from cell and callus cultures of cassava, using reproducible procedures, currently constitutes the main constraint to progress in research in this field.

The probability that genetically regulated factors block shoot differentiation in cassava cell and callus cultures can

By using genotypes with low inbreeding depression, such as those which seem to exist in cassava (Kawano *et al*, 1978b), homozygous lines could be produced quickly through anther culture and chromosome doubling. Tetrasomic inheritance would be avoided in the doubled haploids, which could be used for genetic and physiological studies. The acyanogenic character would be maintained by hybridization with other anther culture-derived lines.

Hybrid seed may offer an alternative to the growth of cassava in the future. Because of inbreeding depression it is difficult to produce pure lines for use in hybrid seed production through successive inbreeding. Homozygous lines could be quickly produced from selected materials, thereby facilitating the maximization of heterosis in cassava.

Certain specific traits such as acyanogenesis or any other simply inherited trait (Hrishi, 1978) that may drastically affect an otherwise highly desirable cultivar, could be amenable to rectification through mutation techniques or induction of intracional variability. Vegetative cassava buds have been treated with mutagens (Nayar, 1975). Changes in stem and leaf morphology and cyanide content were observed after treatment with gamma radiation. Increases in ploidy as well as in protein content were produced with the use of colchicine. It may be possible to expose cell cultures-preferably haploid- or even meristem cultures to acute and chronic radiation as well as to chemical mutagens and select desirable phenotypes. If, for instance, cyanide freedom is due to a recessive mutant gene, such treatments could give rise to material with altered glycoside content.

The use of haploid cells in mutation work would facilitate mutant selection since both recessive and dominant mutants would appear immediately and could be stabilized through chromosome doubling. Haploid propagates could be even more amenable to mutagenesis than cell and meristem cultures since the latter do not consist of single cells and can not be subjected uniformly to mutagenic agents (Gamborg *et al*, 1974).

Haploids could also help breeding efforts if they are able to provide any phylogenetic clues on the nature of allopolyploidy in cassava. Furthermore, haploids could help in the determination of genetic ratios and gene action. Since dominance effects are absent in doubled haploids, the method could also serve to detect lethal genes which may have accumulated in heterozygous clones.

Vegetative propagation of cassava is an advantage in cell culture manipulations. Once valuable variability has been selected, its genotype can be maintained through vegetative multiplication. Even epigenetic variability, common in tissue culture and stable through mitosis (Carlson, 1979), could be

198

maintained vegetatively. Because of vegetative propagation, chimeral plants would be regenerated from mixed callus of different genotypes (Carlson, 1977).

Finally, the future would witness important development in molecular biology and genetics which would allow manipulation of cassava cells or protoplasts with physical stresses, specific pathogenic toxins, or metabolic analogs to select valuable phenotypes. The exchange of genetic information through cell fusion, organelle uptake, or DNA transformation processes would pave the way to the application of genetic engineering schemes to cassava.

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# CHAPTER III


# AGRONOMIC PRACTICES


AGRONOMIC PRACTICES FOR CASSAVA PRODUCTION: A LITE-
RATURE REVIEW

INFLUENCE OF PERIOD AND CONDITIONS OF STORAGE ON
GROWTH AND YIELD OF CASSAVA

MINERAL NUTRITION AND  FERTILIZATION OF CASSAVA.

FUNCTION OF VESICULAR-ARBUSCULAR MYCORRHIZA FOR
CASSAVA GROWTH.

# AGRONOMIC PRACTICES FOR CASSAVA PRODUCTION:

## A LITERATURE REVIEW

Julio Cesar Toro M.*
Charles B. Atlee

ABSTRACTS

This paper reviews the main agronomic practices for cassava. Cassava production requires good soil preparation, and, specifically, soil drainage must be adequate. The stakes must be fresh and come from mature healthy plants from which the most lignified part of the basal stem is preferred. The stakes' quality and size are of fundamental importance if high yields are expected. Stakes with signs of cankers, galls, tumours, galleries, or insect infestations should be eliminated, and 30 cm stakes are highly recommended.

Plantin on the flat can only be done in areas where root rot is not a serious risk. The vertical planting position is generally recommended, especially in regions with erratic rainfall because it ensures better contact with available moisture thus provoking faster sprouting. It also gives better and more uniform distribution of roots, and, hence, better anchorage and protection against lodging. The most recommended planting time is the beginning of the rainy season, but in areas where plant diseases are prevalent, planting is usually done at the end of the rainy season.

In general, poor soils show good response to plant population increases, but in rich soils the cassava production, 10,000 plants/ha is recommended unless local research indicates otherwise. Proper selection and treatment of planting material will ensure a sprouting percentage so high that no replanting is needed.

Good weed control, either manually or chemically, is probably the most important factor in obtaining high cassava yields. There are about 19 selective herbicides recommended for cassava. Because of its exceptional ability of extract nutrients from

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the soil, cassava is usually the last crop to be planted in a rotation scheme. It is advisable to leave the land fallow or rotate following the second or third consecutive harvest, especially in medium-to-poor fertility soils.

It is concluded that the most important cultural practices for cassava production are the selection of healthy and mature 30-cm stakes and good weed control. These practices apply everywhere.


INTRODUCTION


The aim of this literature review is to presente a more thorough and up-to-date coverage of the main agronomic-cultural practices used to produce cassava in various parts of the world. No effort has been made to list all references, only selected ones mostly published during the past 20 years. Both fertilization and multiple cropping have been omitted.

Much of the literature is repetitive; however, some excellent work has been done during the past 10 years with the emphasis on cassava research at several national and international research centres. Until recently most agricultural researchers had overlooked cassava, even though it is the seventh most importatnt crop in the world. One reason is that it is primarily a subsistence crop grown in tropical countries (Nestel and Mac Inteyre, 1973). Although grown in more than 60 tropical countries, it has assumed major importance in only six countries that account for nearly two-thirds of the world production.

Although experimental yields greater than 70 t/ha have been obtained, the average yield of cassava worldwide is only 9.4 t/ha. Cock (1974) has suggested that yields in farmers' fields are low because of the lack of suitable varieties and poor agronomic practices.

Cassava is an extremely efficient producer of carbohydrates. It is a native of tropical America, tolerant to drought, grows fairly well in poor soild with low pH, and is relatively resistant to disease and insect pests. It has no precise maturity and can ba left in the ground and harvested nearly any time of the year, thus being a good security against famine. Its potential yield is greater than for other crops that have been researched extensively. Production of calories per hectare per day is higher than for any other staple food crop. Its foliage can produce up to 5 tons of crude protein per hectare a year (Moore, 1976). According to recent FAO projections for cassava, present world production is about 110 million tonnes, equal in dry matter to nearly 40 million tones of grain (FAO, 1978). Of this production, approximately 60% is used for human food. It

is an important staple in the diet of more than 500 million people. The rest is used as livestock feed or is converted to starch or alcohol for industrial purposes. Cassava is extremely perishable when harvested fresh, but if dried or processed it can be stored like most cereal grains. Although not much cassava is consumed in Thailand, it has become that country's major export crop agter rice.

Brazil, the largest cassava-producing country, is presently growing a considerable amount of cassava for alcohol production to be used as a gasoline supplement.

## LAND PREPARATION

As for any other crop, cassava production requires good soil preparation. Land preparation practices vary considerably, depending mainly on climate, soil type, vegetation, topography, degree of mechanication, and other agronomic practices (Seixas, 1976).

Where no mechanization is available and cassava is grown as the first crop in forest clearings, no preparation is required, other than removal of the forest growth by cutting down small rees, shrubs, and vines, and cutting off the branches of large trees to admit sunlight. Trees and bushes are piled and burned at the end of the dry season (Viegas, 1976). When the first rains soften the ground, the soil is loosened with a hoe, planting stick, or sharp instrument, so that the cassava stakes can be easily planted. Grace (1977) reported that the layer of ashes left after burning increases the amount of potash available to the cassava crop.

Where mechanization is available, many cassava growers plow and disk the land to prepare a good seed bed, aerate the soil, and control weed. In Brazil a common practice is to open furrows 10-20 cm deep so that stakes can be planted horizontally. Ribeiro Filho (1966) has suggested that on steep land these furrows be made on the contour to prevent erosion, a serious problem in sandy soils, especially during the first few months of the crop. Plowing and first disking should be about 30 days before planitng (EMBRAPA/EMBRATER, 1976). The second disking should be done just before planting to improve the soil condition and eliminate weed seedlings.

Tineo (1976) has recommended plowing to a depth of 25 cm and then harrowing. In poorly drained soils, ridges should be 15 cm. According to Diaz (1978), in heavy textured soils where danger of root rot exists, cassava must be planted on ridges in accord with experimental results obtained at the CIAT Cassava Program.

Seixas (1976) found no significant difference in cassava yields from soil plowed to depth of 10 cm, 15 cm, or 20 cm, but results could be different in heavier soils.

Normanha (1976b) has suggested that plowing and disking should loosen soil to a depth of at least 20 cm, the depth at which most roots grow. This provides for easy root penetration.

In light, sandy soils, land preparation requires a minimum energy expenditure, and planting is on the flat. However CIAT (1976) has reported that planting on ridges makes harvesting easier, even though yields are sometimes slightly lower than on the flat. Tractor time is 8.40 h/ha for flat planting compared with 12.60-15.33 h/ha for ridges, depending on the height and shape of the ridge.

Santos (1967) found that the percentage of sprouting and yields of cassava were significantly influenced by the method of land preparation. The ordinary method, consisting of harrowing, plowing, harrowing, and making furrows before planting, gave the highest percentage of sprouting and the highest yields (17.6 t/ha). The harrowing-plowing-planting treatment followed (14.9 t/ha). Next were the plowing-planting and harrowing-punching-hole treatments, yielding 15.5 and 10.6 t/ha respectively.

Land preparation, according to Tan and Bertrand (1972), is usually started in the dry season, except in regions with a very humid climate. In the latter, land is prepared at the end of the "heavy rain" season, and stakes are then planted at the beginning of the dry season during which they can take advantage of the lighter rainfall for early root development. Also in lower rainfall areas, earlier plowing is sometimes necessary because the soil is too dry and hard for tillage during the dry period.

In large plantings, the land is usually prepared as for maize; the field is plowed to a depth of at least 20 cm and is then disk harrowed. Planting is done in rows on the flat surface, although heavy soils in humid areas demand "banking" or making beds on ridges at least 15 cm high so that drainage is improved and root rot minimized. In some cases a second plowing in needed before the harrowing. Many farmers in southeast Asia plow to a depth of only 15 cm, but this practice frequently results in a decrease of root yield.


STORAGE OF STAKES


For best results in any cassava production enterprise, fresh stakes from mature plants are ideal. However, when they are not available because of cold, prolonged drought, or even excess moisture, amny producers have to depend on the reliability of

methods to preserve them. Common storage practices usually
cause poor causes loss of moisture and exposure to the attack
of pests.

Bertoni (1945) indicated that, in Paraguay, stakes stored
in a dry place maintained their viability after 5 months. He
also stated that a sample of stakes that showed sign of a rot-
ting disease were used as planting material after 6 months of
storage in a wood house during the dry season.

Mendes (19490 recommended that stakes be piled in a well-
ventilated, shaded area under trees or a straw roof where direct
sunlight and dampness are avoided. With this method, stakes
have been kept in southern Brazil for 3-5 months with deteriora-
tion.

Kiernowski (1950) in Argentina used three cassava varieties
stored in straw piles, straw clamps, damp straw huts, dry straw
huts, and dry shaded areas and found that storing in damp straw
huts and dry straw huts gave the best results. He also conclud-
ed that the response to storage varies according to variety and
moisture and to the method of placing stakes under straw.

Stephens (1965) stated that, for any storage methods some
factors must be kept in mind: stakes must be mature when stored;
stakes must not be stored wet or allowed to get wet; and stakes
must be covered lightly at first so that surplus moisture can
escape and covered more heavily later as protection against the
cold.

Sanchez and Rodriguez (1967) studied three methods to pre-
serve cassava during winter in the province of Misiones, Argen-
tina. Stakes were stored vertically and horizontally in a straw
hut in a forest, and in an open field. In all cases stakes were
covered with soil, straw, or both. The stakes that were stored
horizontally and completely covered with soil in a straw hut
were preserved best.

Krochmal (1969) stated that uncut stems are usually stored
in shady, well-ventilated areas. In southern Mexico the bundles
of stakes are kept upside down under mango trees for as long as
8 weeks. In the south of Brazil, stakes are stored up to 8
weeks, amny times horizontally in the open during the cool dor-
mant season (July and August).

In India, stakes are tied in bundles and stored upright in
shade or ventilated sheds for up to 6 weeks. If the crop is
harvested during heavy rainfall, storage is limited to 10 days.

CIAT (1972) found that stakes kept at 4°C for 29 days did
not sprout, whereas stakes with both ends protected with a fun-
gicide were viable for 65 days. When the tips of the stakes

211

were immersed in liquid wax, the viability was increased to 85 days; in this case, wax was removed at the time of planting.

Castellar and Mogollón (1972) mentioned that in Caribia, Colombia, stakes of 30 and 50 cm covered with banana leaves were stored for 40 days with optimum results. The viability of stakes longer than 30 cm was improved when the tips were dipped in wax.

CIAT (1973) cited findings that stakes longer than a metre have been kept for up to 3 months with the central portion viable; however, stakes shorter than 25 cm deteriorated rapidly. Also cited were findings that stakes with paraffin waxed ends, when compared with unwaxed stakes in an investigation of moisture loss, did not exhibit reduced fresh weight. Storage position did not affect overall storage behaviour. although stakes stored in the inverted position had delayed bud breaking and horizontally stored stakes produced a larger proportion of shoots from nodal buds than did stakes in either vertical or inverted positions. The moisture content of stakes fell from 67 to 46% after 50 days storage at room conditions. Waxing was not recommended for storage.

CIAT (1974) showed that long stakes wrapped in sacking and stored in a pal-thatched shelter maintained viability better than short or unprotected ones. After 2 weeks, shoots appeared from the apical end of the stakes. The shoots grow, thus exhausting the reserves of the stem and transpiring water.

CIAT (1978) treated 70- and 20-cm stakes of two varieties (one with good sprouting ability and the other with poor ability) by dipping them in Bavistin and Orthocide (2000 ppm a.i. each) and found varietal differences in sprouting after storing them in shade. It was concluded that treatment with fungicide prevents losses due to storage.

Lozano *et al* (1977) recommended that the storage area should be well-shaded with some light but not excessive relative humidity (about 80%) and with a moderate temperature (20-23°C). An additional treatment before planting with fungicides favours sprouting even more. He also indicated that although it is not known whether there is varietal resistance to factors affecting stakes during storage highly significant varietal differences have been found.

CIAT (1979) to solve some of the stake storage problems found that dehydration was prevented by storing stakes in polyethylene bags or by treating with sodium alginate (Agricol), a water-soluble gel. A dry film of this gel allows oxygen interchange and prevents water loss. To avoid damage by insects and diseases, CIAT trated stakes before storage with fungicide-insecticidal solutions. Ninety percent of the 20-cm states

212

rooted, and buds sprouted after 12 weeks of storage when treat-
ed with Captan/BCM and kept in polyethylene bags at room temper-
ature.  About 95% of the 20-cm stakes from long stems (70 cm)
rooted, and buds sprouted when stored for 10 weeks on a dry
floor at room conditions (24°C, 80%RH) after treatment with
Captan/BCM (2000 ppm a.i. each).  Similarly, 90% of the 20-cm
stakes rooted, and buds sprouted after 90 days of storage when
they were dip treated in a Captan/BCM (3000 ppm) plus sodium
alginate (10,000 ppm) solution and kept at room conditions.
Treating stakes immediately after harvest regardless of later
storage time increased yield of fresh roots per hectare.

Corea (1977c) for the state of Minas Gerais, Brazil, re-
commended that, when storage is necessary, long stems be plac-
ed in a vertical position and the 10-cm base covered with soil
and straw as protection against desiccation.


STAKE SIZE


In any production system, size and quality of the stake
are of fundamental importance if high yields are expected. Ac-
cording to Lozano *et al* (1977), the quality of the stake per
se is determined by the age of teh stem used, the number of
nodes per stake, the thickness of the stake, the size of stake,
varietal differences in sprouting duration of storage, and the
extent of mechanical damage to the stake when it is being pre-
pared, transported, stored, and planted.

A cassava plant may be obtained from a very small stake,
with only one bud (Cock *et al*, 1976), but the possibilities of
sprouting under field conditions are very low especially when
soil moisture is deficient.  Celis and Toro (1974a,b) indicat-
ed that early development is affected if planting is done in
poor soils because the nutritional reserves are insufficient
in a small stake for initial growth stages.  They also said
that the smaller the unburied portion of the stake, the tougher
the competition with weeds.  The advantages of using very long
stakes, i.e. 60 cm long, are higher initial height of the plant
and, hence, greater shading of the soil surface, which increases
the ability of the cassava plant to compete with weeds.

The length of stake commonly used by farmers is 15-25 cm,
which seems appropriate unless a field trial that includes pro-
duction costs indicates a more convenient size.  It has to be
kept in mind that economic aspects as well as practical consi-
derations about handling the stake may affect the size of the
propagating material.

CIAT (1975), working with local varieties in three differ-
ent locations using 20-, 40-, 60-, and 80- cm stakes planted

213

vertically, obtained the best results with 40- cm stakes without irrigation.

Gonzales (1973) in Jusepin, Venezuela, using 10-, 20-, 30-, and 40- cm stakes planted horizontally, vertically, or in an inclined position in rain-fed conditions for 2 years found no difference that could be traced to planting positions but found that 40- cm stakes always gave the highest yields. In contrast, CIAT (1979) using 20-, 40-, and 60- cm stakes planted vertically at the CIAT-Palmira experiment station under irrigated conditions found that 20- cm stakes yielded significantly better than the other two. Rosas (1969) in La Molina, Peru, using three planting positions and stake lengths of 10, 20, and 30 cm found no yield differences due to planting positions but found that the 10- cm stakes gave the highest yield. Silva (1970) reported that experiments in the state of Santa Catarina, Brazil, with stake lengths of 10, 15, 20, 25, and 30 cm have indicated that 30- cm stakes are superior. Normanha and Pereira (9164) recommended stakes, 20- 25 cm long, planted horizontally, 10 cm deep, for Brazil in general. Chan (1970) in Malaysia found no differences in yields using stakes 8, 15, and 23 cm long.

Gurnah (1974) in two experiments carried out during 2 years in the forest zone of Ghana with adequate rainfall (1080 mm) using stakes of 2, 3, 4, 5, 6, 7 and 8 nodes found that yield increased with the number of nodes up to five. An increase in the number of nodes beyond five per stake did not affect yields. The longer stakes had more buried nodes than did the shorter ones and presumably produced more stems and leaves and in turn higher yields. Also, Donkor (1971) observed that when more nodes are buried, more roots and stems are initiated. However, it must be pointed out that the stakes used in his experiments were from freshly cut stems. If the stems had to be transported over long distances or stored for a long time before planting, hardiness and ability to survive storage would have been important, the more mature basal and middle stakes probably giving better sprouting and possibly better yields. During Donkor's experiments, there was adequate, well distributed raingall. It is likely that if there had been no rain for a long period after planting, the types of stakes also would have made a difference, as top stakes are most likely to suffer from lack of rain. In the forest zone, where raingall is plentiful, any type of stake can be used reliably.

Jeyaseelan (1951) working in Ceylon (Sri Lanka) with basal and apical stakes, 15 and 30 cm long, and investigating horizontal and vertical planting positions found that best yields were obtained with 30-cm stakes from the basal part, planted vertically.

Rodriguez and Sanchez (1963) in Misiones, Argentina, in a

3-year study using 30-cm stakes and two planting positions (inclined and horizontal) and comparing the results with those from 10-cm stakes planted horizontally, found that the 30-cm stakes gave higher yields, as did the inclined position, although the latter made harvesting difficult.

Conceição and Sampaio (1973a) for 3 years in Bahia, Brazil, used 10-, 12-, 15-, 20-, 25-, and 30-cm-long stakes from 12-month-old plants in sandy, clay, loam latosol with 1196 mm of rain and 24°C. Stakes were planted horizontally, 10 cm deep. They found that high yields were obtained with 20-, 25-, and 30-cm stakes.

Jennings (1970) suggested that long stakes gave higher yields than short ones. He recommended 30- and 45-cm-long stakes (moderately thick), taken from the basal part of the plant rather than from terminal parts.

PLANTING METHODS

Whatever planting method is used, good sprouting of the stakes requires adequate soil moisture and good soil preparation. Land preparation and the corresponding planting methods depend primarily on soil type and climate. Toro *et al* (1978) reported that studies carried out by CIAT, on the flat plains of Colombia, showed that flat planting is advantageous when done during the dry season. Ridge planting was desirable during the rainy season. A "bed" system, developed at CIAT, uses a flat-top ridge. The beds are made by a shaper attached to a rototiller; therefore only one operation is needed to prepare the land for planting. (Beds or ridges are not recommended for sandy soils because they will not hold their shape, and, in any case, such soils have good drainage.) Beds are somewhat more practical than ridges for intercropping cassava with beans or cowpeas, which can be planted mechanically at the same time as cassava on a heavier soil. When machinery is not available to make ridges or beds, cassava can be planted on the top of a cone-shaped hill or mound built manually with a hoe (Toro *et al*, 1978).

As Normanha (1976b) also indicated, heavier, more compact soils should be prepared in beds or ridges. Heavy soils that seal or whatelog have a detrimental effect on cassava during the rainy season because of poor aeration. Without adequate oxygen, the cassava cannot form storage roots, probably because starch accumulation needs large quantities of free oxygen.

In 1976 Conceição reported that horizontal planting, 10 cm deep in furrows, facilitates commercial harvesting and reduces weed problems. Ezeilo *et al* (1975) found that in Nige-

ria cassava is grown on lighter soils and that 77% is planted on hills, 11% on ridges, and 11% on the flat. In Malaysia, Lulofs (1970) reported that planting on the flat is satisfactory but ridging May give a more even stand, easier harvesting, and better erosion control.

Lozano and Terry (1978) recommended that, in areas where rainfall is more than 1200 mm, clay soil should be prepared in ridges to promote better drainage, which improves crop stand and yield considerably. Yield losses of 80% caused by root rots have been reported. However, Koch (1916) found no significant difference in yield between planting on the flat or on ridges, and Grace (1977) wrote that some experiments have shown ridging to produce somewhat lower yields than flat planting. Harper (1973) also reported that planting on ridges in Thailand produced lower yields than did flat planting. In one experiment with commercial-sized plots conducted in the loamy soils of the Caicedonia area, CIAT (1976) reported similar results: however, ridging reduces weedings and facilitates harvesting.

Krochmal (1969) stated that planting on furrows or ridges is a rare practice and not one to be encouraged because machine planting is impossible with such systems and the costs of the additional operations do not pay off in any increased returns.

PLANTING POSITION

Like the literature on planting methods, that for planting position varies with cassava variety, soil characteristics, and climate.

Galang (1931) in the Philippines using 30-cm stakes of 21 different varieties found that 13 gave higher yields when planted vertically, whereas the remaining eight responded better to an inclined position. After two experiments he concluded that stakes may be planted in either an inclined or a vertical position with practically equal results. But, Fernando and Jayesundera (1942) indicated the significant superiority of vertical planting over horizontal. Later, Rao (1952) stated that vertical planting is superior where rainfall is more than 1700 mm a year.

Brandao (1959) compared two systems of planting cassava in heavy soil. Basal stakes, 40 cm long, planted vertically 10 cm deep, yielded 30% more than 20-cm stakes planted 10 cm deep horizontally. The root distribution was different, with roots being nearly 5 cm deeper from vertically planted stakes than from those planted horizontally. The latter were easier to harvest.

Crawford (1961) working in Jamaica came to the conclusion that horizontal planting of 25-cm stakes is best if soil moisture is limited at planting time. If the stakes are covered with 2-3 inches (5-7 cm) of soil, there is less "drying out" and therefore sprouting percentage is improved. Roots originate from a greater number of points along the length of the stake and therefore have more room to develop; they also tend to spread and develop closer to the soil surface, making better use of applied fertilizer and organic matter. Horizontal planting gave higher yields than did inclined plantings (an angle of 15 or 45 degrees).

Loria (1962) in Costa Rica studied three planting positions, horizontal, inclined, and vertical, and found no significant difference in yield although vertical planting produced the highest yield. Similarly, Chan (1970) found no differences in yield from horizontal, vertical, or inclined planting of 15-cm stakes. On the other hand, Krochmal (1969) in the Virgin Islands reported that it would be better to plant 20- or 25-cm stakes with three buds, horizontally at 5-10 cm under the soil surface than to have them inclinded. Kunju (1972) indicated that, when stakes are planted on ridges, vertical planting is always found to be better.

Harper (1973) in Thailand found that the planting position depends on soil and climatic conditions. Generally horizontal planting is carried out in the dry season (October to May), producing more sprouting and greater yield due to the fact that roots are produced from more growing points. Also roots tend to grow nerarer to the surface of the soil, which makes harvesting easier. Vertical or inclined planting is used in areas where raingall is high during the wet season (May-October) or where horizontal stakes would rot, such as in areas with high soil moisture.

Gonzales (1973) in Venezuela made a study involving two tests on size and planting position. He used four sizes: 10, 20, 30, and 40 cm and three positions: vertical, inclined, and horizontal. In both tests, the 20-, 30-, and 40-cm stakes, were significantly superior to 10-cm stakes, and he, therefore, recommended continued research using 20- to 40-cm stakes. With respect to planting position, the results of the first test gave 15.0, 13.7, and 12.0 t/ha respectively for horizontal, vertical were superior there was no significant difference between the two. In the second test yields from the three positions were not significantly different, ranging from 22 to 23.8 t/ha. The lower yields of the first test may have been due to deficient rainfall.

In other work on planting position, some workers found no significant difference in yield but a decided difference in depth and root distribution (Gurnah, 1974). Vertical planting

217

produced roots that were deeper and closer together, whereas horizontal planting produced shallow roots distributed along the length of the stake.

Cock (1974) stated that studies on planting position do not show consistent trends.

Chew (1974), with cassava grown in Malaysian peat soils for 2 years, used horizontal, inclined, and vertical planting and found no significant difference in yield from the three positions. However, he recommended horizontal planting because it provides better protection against desiccation of stakes and also gives better sprouting.

Conceição and Sampaio (1975a, c) undertook an experiment involving four planting systems with four cultivars. The effect of the planting system was not statistically significant; consequently it was recommended to plant on the flat using 20-cm stakes planted horizontally at a depth of 10 or 20 cm because it would be less expensive for mechanical planting.

Wahab *et al* (1977) found no significant difference in yields from manual and mechanized horizontal planting in Guyana.

In Colombia, Diaz *et al* (1977) observed that cassava was widely planted in the vertical position in only one of the five cassava-growing areas they studied. This region was characterized by sandy soils with a prolonged dry season (up to 4 months) and a mean annual rainfall of 1200 mm.

According to Grace (1977), under low rainfall conditions, vertical planting may result in the desiccation of the stakes, whereas in areas of higher raingall, horizontally planted stakes may rot. In general, horizontal planting, 5-10 cm below the soil surface, is recommended in dry climates and when mechanical planting is used. This system makes manual harvesting easier too. Vertical planting is used in rainy areas and inclined planting in semi rainy regions.

Castro *et al* (1978) determined that neither the cut angle nor the planting position of the stake had a significant effect on yield. With the right-angle cut, the roots were distributed uniformly around the perimeter. With horizontal planting, harvesting and separation of the roots was easier compared with vertical or inclined planting. A right-angle cut and vertical planting position were recommended because of a slight tendency toward higher yield. The horizontal position was recommended for mechanized planting when soil moisture is adequate.

Onwueme (1978a) by using 20- to 35-cm stakes planted vertically upright and inverted found that yield was significantly higher for the upright planting.

218

Celis and Toro (1974a, b) recommended that for vertical planting at least four buds should be underground for good sprouting. In this position, roots tend to form at the lower end of the stake and are distributed radially, more or less uniformly. Inclined planting means inserting the stakes in the soils at a 45-degree angle. In this case the roots tend to follow the same direction of the angle at which the stake is planted. Some farmers think that harvest labour is easier with this method because of the position of the roots. Horizontal planting involves placing the stake horizontally, usually in a furrow, and burying it completely. This planting position lends itself well to mechanical planting. In this position roots tend to form at the butt end of the stake. When stakes are long (30-40 cm), roots may form along the sides at the nodes.

In tests at CIAT, sprouting and emergence of stakes under field conditions were always more rapid with vertical planting than with any other method. Even though there are good reasons and clear advantages to planting cassava stakes vertically, there are also some advantages to horizontal planting: (1) horizontal planting is easier; (2) there is no need to worry about planting stakes upside down, which Bolhuis (1939) showed to be undesirable; (3) there is no need to stoop or bend over (Odigboh, 1978); and (4) the roots are shallower and easier to harvest. However, some of the obvious disadvantages are: (1) under extremely adverse climatic conditions, the shallow (5 cm) planting allows more heat damage, more exporisre of roots to erosion effects, and more lodging from wind (Koch, 1916 and Castro, 1979), due to poor anchoring in the ground; (2) deeper planting (10 cm) can cause slower sprouting and emergence, resulting in more weed competition (Castro, 1979), and during weeding more damage to stakes that have not yet emerged (Ribeiro Filho, 1966); and (3) sometimes lower commercial yields are produced than with vertical or inclined plantings.

In sum, experience in many cassava-growing areas of different countries jas indicated that planting position should be decided according to the following criteria:

1. In regions of medium to heavy soils with adequate rainfall (1000-2000 mm/year) it does not matter whether stakes are planted horizontally, inclined, or vertically because the moisture will be adequate for sprouting of the buds.

2. In areas of sandy soils or erratic rainfall, vertical planting is safest. In this case, 20-cm stakes will have at least 10-15 cm in the soil, and thus have better contact with available moisture. When stakes are planted horizontally in such regions, the buds will rot because of the hear, which is always greater in the soil than in the surrounding air. In the case of vertical planting, the stakes serve as a hear dif-

diffuser (Lozano personal communication, 1975).

## PLANTING DATES - TIME OF PLANTING

The most common planting time for cassava is at the beginning of the rainy season when competition for labourers for planting is at its peak. In areas with adequate temperature and soil moisture during the dry season, planting can be done at almost any time when labour is available. Planting in the dry season also reduces disease problems and increases yields. It is advisable to plant after the first well-defined rains to avoid losing the plants. Research done by Normanha and Pereira (1947) in São Paulo, Brazil, indicated that planting cassava during the normal harvest (May-July) produced the highest yields and starch content: This timing would also solve the problem of storing planting material and would result in less soil erosion than planting during September and October after rains begin. Correa (1977c) stated that in other areas of Brazil it is advisable to plant at the beginning of the rainy season, which in Minas Gerais is October- mid-December, or during the rainy season in drier areas such as Bahia (April -June). Albuquerque *et al* (1974) cautioned against planting during October-January in eastern Para in the Amazon Valley because that is the wettest period and rotting can be a problem. Viegas (1976) however, recommended October planting in northeastern Brazil, all cultivars should be planted in August (or October in dry years).

Silva (1979) recommended planting at the beginning of the rainy season, but Ribeiro Filho (1966) indicated that earlier planting is recommended by Normanha and Pereira for Sao Paulo and Drumond for Belo Horizonte.

Many factors that could influence soil moisture such as the texture of the soil, rainfall, relative humidity, temperature, and wind; in heavy, poorly drained soils excess moisture encourages root rot (Oliveros *et al*, 1974). Lozano and Terry (1978) stated that appropriate planting time may reduce the incidence of disease. For instance, planting at the beginning of the rainy season ensures good establishment and ensures sufficient growth of the canopy to provide shade during the dry season, approximately 4 months after planting. Because of the dry environment (in spite of poor air circulation and high relative humidity between plants), the microclimate will not be favourable to pathogens. For this same reason, planting has been recommended at the end of the rainy season in the eastern *llanos* of Colombia.

In many cassava-growing areas, rainfall is evenly distributed throughout the year and offers the possibility of several

different planting dates with only mirror differences in yield especially where soils are well drained yet maintain moisture. Two planting dates have been recommended for the Philippines and Colombia because of two rainy seasons per year.

According to Correa (1971), the timing of planting is the most important production factor. Zijl (1930) also stated that planting dates markedly influence production and recommended November planting for Java (Indonesia). Celis and Toro (1974a, b) commented that probably the most important factor related to time of planting is lack of moisture, which during the first 20 days after planting may cause serious losses in sprouting.

Viegas (1976) stated that although planting should be done at the beginning of the rainy season it is important to plant only on a clear, dry day. One problem with waiting until after the rainy season is well under way is taht good propagation material may be difficult to find. If stems have already started to sprout, the sprouts are easily broken off in handling, and if stakes have been stored for a long time, they become dehydrated and lose their sprouting vigour.

An experiment, reported by Rodriguez *et al* (1966), was conducted in the Misiones province of Argentina, over a 3-year period. The findings were that one variety was best planted early (August-September) and harvested in May and that another was best planted late (October-November) and harvested in June. In other words, specific varieties may each have different optimum planting and harvesting dates. This is probably the reason that many subsistence farmers plant several different varieties throughout the year so that they can have cassava to harvest at any time.

In 1977, Grace indicated that time of planting is influenced by both weather conditions and the availability of planting material. Planting is sometimes divided between the two rainy seasons, but is usually carried out throughout the year in regions with year-round rainfall. It is desirable to plant and harvest during approximately the same season to avoid storing the stalks for a long time. Experience has shown that starch production in the cassava plant is best when planting takes place at the beginning of the rainy season.

Ninam *et al* (1977) found that in Kerala, India, cassava can be grown all year and that for maximum root yields, planting should be done in April. The second best season for planting is September. Nair (1978) recommended April-May as the best time for planting in Kerala and Tamil Nadu where the climate is warm and rainfall is 1500 to 2000 mm/year distributed evenly.

PLANTING DEPTH


Normanha and Pereira (1950), using three depth (5, 10,
and 15 cm) and two planting seasons during 3 years, concluded
that under hot dry conditions stakes planted 15 cm deep sprout-
ed faster than did those planted at shallower depths perhaps
because of increased moisture at the 15 cm depth. The opposite
was true when temperature and moisture were adequate. The har-
vest was much easier for stakes plantes at 5 cm deep than for
those planted at 15 cm because of the rooting depth of the lat-
ter. The yields were 18.2, 16.5 and 13.2 t/ha for stakes 5,
10, and 15 cm deep, respectively. The planting depth of 5 cm
was quite advantageous but had drawbacks, such as the lack of
protection against erosion and lodgingm that made a 10-cm
planting depth more suitable.

Campos and Sena (1974), to measure the rooting depth of
cassava, planted 20-cm stakes in rows 10 cm deep in a horizon-
tal position and spaced 1.00 x 0.60 meters apart. The results
showed that the roots reached depths of 90 and 140 cm at 140
and 365 days, respectively. Within the 30-cm depth were found
95.3 and 96.4% of all roots, and of these 65.6 and 85.7% devel-
oped in the top 10 cm of soil.

Conceiçao and Sampaio (1975a, c) recommended the flat
planting of 20-cm stakes, 10-20 cm deep in a horizontal posi-
tion, because this lowers the cost per hectare for mechanical
planting.

In Brazil it is recommeded that cassava be planted in con-
tinuous rows horizontally 10-15 cm deep and that animal- or
tractor-powered machines be utilized.

Holguin *et al*(1978) found that, under optimum conditions,
such as adequate soil moisture and good quality treated stakes,
planting depth did not affect the growth or yield of cassava
planted vertically. The 10-cm planting depth for the vertical
position was easier for both planting and harvesting. This
study should be repeated in light sandy soils with little mois-
ture because under adverse conditions these soils become extre-
mely hot and dry at a depth of 5 cm and would create a most un-
favourable environment for sprouting and rooting of cassava
stakes (Normanha and Pereira, 1950).

Ribeiro Filho (1966) suggested that deeper planting makes
harvesting more difficult, and Celis and Toro (1974a, b) noted
that stakes can be planted shallow or deep in any one of sever-
al positions. A good practical rule is that cassava stakes
planted in dry sandy soil should be inserted relatively deep,
whereas those in moist, heavy soil require shallow planting.
In the latter case, it should be remembered that a deep plant-

ing will make harvest difficult and increase production costs.

In 1972, Tan and Bertrand commented that depth of planting must be regulated in terms of environmental conditions. Too much exposure of the stakes in areas where soil moisture is below optimum can result in poor stands and consequently low yields.

## MECHANIZED PLANTING

According to Normanha (1970), the highest degree of cassava crop mechanization in Brazil has been reached through the use of a two wheeled mechanized cassava planter, made in Brazil, which simultaneously acoomplishes furrowing, fertilizing, horizontal planting, covering of stakes, and firming of the soil. It is tractor pulled and plants two rows at a time.

At present, the need for a more efficient machine for planting is becoming very important, especially where large areas have to be planted in a short time. The old Sans two-row planter is very heavy and requires stakes already cut. This latter "drawback" may be useful because the stakes can be treated prior to planting. Massey Ferguson also has a two-row planter, ligher than Sans. This planter opens up the furrow, cuts the stakes to the size desired, deposits them in the furrow, places fertilizer on either side of the stakes, covers them with soil, and compacts the soil if required. It has a planting capacity of 3-4 hectares per day. The Delfosse machinery manufacturers in Montes Claros, Minas Gerais are engaged in developing cassava planters for 4-6 rows.

Monteiro (1963) reported that the Sans planter was tested at Picacicaba, Brazil, and it did an almost perfect job. It operates at normal tractor speed even on fairly steep land. Using it, eight persons can plant 10 ha/day, whereas 30 persons are needed to plant the same area by hand.

Leihner (1979) stated that implements of the vegetable or tovacco-transplanting types should be looked at for possible adaptation to vertical planting. Mechanization in grain-legume planting has existed for a long time and cannot be considered as a technical problem but an intercrop planter would have to combine the different elements of the single crop planters into one machine. Cock (personal communication, 1978) indicated that the cassava program of Cuba has developed a planter prototype for vertical planting.

According to Odidboh (1978) the manual planting of cassava stakes. in a vertical or inclined position, is an arduous and backbreaking operation and constitutes one ot the major factors limiting the development of large scale cassava indus-

tries in Nigeria. So the development of a new two-row cassava planter in that country may be particularly important. The machine is fully automatic, tractor-drawn at speeds up to 10 km/h. It plants stakes of diameters between 2 and 5 and excludes smaller diameters, which have lower viability. Stakes 25 cm long are planted 17 cm deep at inclinations of up to 80° to the horizontal, depending on tractor speed. Spacing is 0.9 m on small ridges that ate 0.9 apart. The metering mechanism is driven by the drive wheels. The machine is quite sensitive to the quality of field preparation, especially at high speeds; 6 km/h is recommended. The within-row plant spacing is practically independent of planter speed. Makanjuola (1975) reported that several units of this automatic planter can be mounted side-by-side for planting more than one row at a time. The machine can be manufactured in Nigeria except for the ridge disks and bearings.

Schulte *et al* (1973) reported good results with a New Holland vegetable transplanter, which planted an average of 0.28 ha/hr. He indicated that it should be possible to develop a transplanter that would make ridges and plant the cassava stakes in one operation.

PLANT POPULATION

Optimim plant density of cassava is highly dependent on edaphiclimatic factors, cassava varieties, soil fertility, cultural practices, and the final utilization of the roots. Calderön (1972) working with two varieties in a fertile soil at populations from 10,000 to 30,000 plants/ha found that yield increased with population in only one of the varieties. CIAT (1976) reported that optimum plant population per unit area depends on the size of the plant. Two short and two tall varieties with different branching characteristics were selected and planted at CIAT at densities between 2500 and 40,000 plants /ha harvested at 12 months. It was found that total root yield increased as plant population increased. This is a good characteristic for industrial cassava cultivation. However, for commercial fresh consumption optimum plant population was 10,000 plants/ha for short and tall varieties of erect type and 5000 plants/ha for tall branched varieties.

Experiment conducted by CIAT (1975) in different zones showed that optimum plant population changed according to ecologic conditions. In general, poor soils show good response to plant population increases, whereas in rich soils the response to plant population increases depends on the growing habit of the varieties. In 1970, Silva reported taht in the southern state of Santa Catarina and the Sete Lagoas region at Minas Gerais it is convenient to plant from 16, 666 to 20,000 plants/ha in soils of good fertility.

Normanha and Pereira (1963) also recomended from 16,666
to 20,000 plants/ha in low fertility soils of the state of
Sao Paulo even if plants are fertilized and 13,888 plants/ha
in fertile soils due to the more vigorous grows in this type
of soil. Nunes *et al* (1976) reported that using nine popula-
tions in three municipalities of the state of Rio de Janeiro
with low fertility soils, he found that 20,000 plants/ha gave
the best result for total roots. He also concluded that for
every 20 cm of extra space yield was reduced by 765 kg/ha.
Drumond (1954) found that in the experiment station of Patos
in Minas Gerais in fertile soil the best population was 20,000
plants/ha; Mattos *et al* (1973) recommended 16,666 plants/ha
for the Cruz das Almas region in Bahia for soils of low fertil-
ity without fertilizer application. Santos *et al* (1972) recom-
mended 10,412 plants/ha for the state of Pernambuco. He also
indicated that for the poor soils of the northeast 20,000
plants/ha is recommended in contrast with 13,888 for the good
fertile soils of the same region. Albuquerque (1970) has re-
commended after many years of cassava research 10,000 plants/
ha for the low fertile soil of the sate of Para in the Amazon
basin, 17,777 for soils of fertility below average, and 4473
for the fertile soils. Mandal *et al* (1973) at the Central Tu-
ber Crops Research Institute found that the highest root yield
was obtained at 12,345 plants/ha for a branched variety and
17,777 plants/ha for a nonbranched variety during a 2-year
study. Consequently, the requirement of spacing for different
types of varieties was ascertained. He also found that with
increases in shoot numbers from one to two shoots per plant
root, yield increased significantly in both branched and non-
branched strains.

Narasimhan and Arjunan (1976) found at Tamil Nadu in India
that by adopting wider spacing in cassava at 12,345 plants/ha
they could minimize incidence of mosaic. In general, it has
been observed that as plant population increases, the total
root yield also increases; however, the number of roots per
plant, root size, and harvest index decrease, while weed con-
trol by competition improves. CIAT (1973) with a systematic
fan design planted three varieties at populations ranging from
2000 to 80,000 plants/ha. At the 7th-month harvest, CMC-84
gave its highest yield (18 t/ha) at populations of between 5000
and 9000 plants/ha whereas CMC-49 produced its highest yield
(18 t/ha) at between 2000 and 5000 plants/ha. The variety Lla-
nera yielded 24 t/ha between 3000 and 7000 plants/ha so it
seems that optimum plant density in cassava changes with var-
ieties. The yield decreases at populations larger than opti-
mum because of the weight reduction in roots.

Tardieu and Fauche (1961) recorded the highest yields of
cassava with 10,000 plants/ha; however, Rodriguez *et al* (1966)
recommended much higher populations 13,300-20,000 plants/ha.
Gurnah (1973) obtained the best yield of roots at populations

225

of 18,500 plants/ha planted at 60 x 60 cm and observed that spacing above or below 60 cm reduced root yields in the forest zone of Ghana. Gurnah's optimum spacing of 60 cm was closer than that (90 cm) generally recommended in Ghana (Doku, 1969). Takyi (1972) observed that spacings of 90 x 90 cm and 90 x 60 cm on sandy loam in ochrosol at Kwadaso, Ghana, gave significantly higher yields than spacings of 90 x 120 cm, but there were few large roots with the closer spacings. Enyi (1970, 1972) used 90 x 120 cm in experiments on cassava in Sierra Leone but Godfrey-Sam-Agrrey and Bundu (1972) spaced experiments at 120 x 120 cm in Sierra Leone. Godfrey-Sam Aggrey (1978) using a multishooter variety in Njala upland soils of Sierra Leone found that increasing plant population to more than 7000 plants/ha decreased all parameters studied except top6root weight ratio, which Increased. The observed effects were attributed to competition for environmental resources, because area of land/plant unit decreased as plant population increased.

The literature with respect to optimum plant populations and yields conflicts both among and within countries. Because the growth habits and morphology of the crop, as well as environmental conditions, influence cassava yields, recommendations on plant populations for one variety in a particular environment may not be appropriate elsewhere or with a different variety of cassava.


REPLANTING


Replanting consists of replacing stakes that for some reason do not sprout 1 month after being planted. If the planting material has been properly selected and treated (Lozano *et al*, 1977), replanting may not prove necessary. Economic considerations are important because a decision must be made about the percentage of sprouting failure at which replanting is economically feasible. By following a careful selection and treatment of stakes, Toro (1979) was able to get 94% sprouting mean in 28 trials with 38 promising and 10 local varieties in 10 Colombian locations during 3 years covering a wide range of ecologic conditions. According to Tan and Bertrand (1972), if a high yield is desired, stakes that fail to develop should be replaced as soon as possible. Grace (1977) suggested replanting no later than 1 month after planting, when at least 5% of plants fail to sprout.

In Caicedonia, Colombia, Ramon Duque (personal communication, 1979) used long-heeled stakes coming from the branching of a mature plant for replanting. The stake was planted in such a way that the long part remained inclined (75°), whereas the heel (about 20 cm) was buried horizontally. The length of

of the stake was always 25 cm longer than the average height
of the crop at replanting time. The replanted stakes sprouted
rapidly and caught up with the rest producing yields comparable
with those from stakes. The use of heeled stakes has been re-
commended by Hartman and Kester (1968).

WEED CONTROL

Good weed control is one of the most important factors in
obtaining high root yields in cassava. According to Ribeiro
Filho (1966),it is especially important during the first months
after planting and during the rainy season. In 1976, Doll and
Piedrahita pointed out that with no weed control cassava yields
can be reduced by 50% but with only minimal weed control cassa-
va has the ability to survive, compete, and produce good yields.
Nearly all researchers agree about the importance of early weed
control when the crop is young and most susceptible to damage
from weed competition for light, water, and nutrients.

Gonzales (1976), Delgado and Quevedo (1977), and Doll *et
al* (1977) reported that weeding represents more than 45% of the
cost of production. This cost is almost entirely for labourers,
who are at times not available because of other priorities.
When weeds are small, they are much more easily controlled than
they are later when they may have already produced an abundant
seed crop.

The number of weedings necessary for cassava varies consi-
derably in different reports, depending mainly on soil fertil-
ity, climatic factors, and varieties. In 1975, Onochie stated
that experiments in Nigeria showed that, when limited labour
is available for cassava production, it should be used for weed
control during the 3rd month after planting. Weeding at this
stage was as effective (in terms of yield) as weeding through-
out the entire greowing period. Santos *et al* (1972) recommend-
ed 3-5 weedings during the first 6 months and 1-2 times the 2nd
year, for the northeast of Brazil; Crawford (1961) suggested 4-
5 weedings during the first 12 months in Jamaica.

Ezeilo *et al* (1975) reported an average 2-3 weedings in
Nigeria, and Diaz *et al*(1977) observed 3 weedings within 6
months of planting in Colombia. Tan and Bertrand (1972) recom-
mended weedings as often as needed until the foliage canopy
closes; according to Doll and Piedrahita (1976) this process
takes 2-4 months. Weeding should begin as soon as weeds start
to compete with the cassava. Delgado and Quevedo (1977) sug-
gested the first weeding be done 28-35 days after planting and
Montaldo (1966) said 21 days after planting plus other times
when weeds begin to be a problem. CIAT (1973) stated that
early weedings about 2 weeks after planting may be harmfull to
young unrooted cassava plants.

227

The amount of weeds and therefore the frequency of weeding depends on a number of factors such as: planting time and prevailing weather - lower soil moisture encourages fewer weeds (Ribeiro Filho, 1966); soil fertility - pH-poor soils or infertile soils may have few weeds (Castro, 1979); vigour of planting stock fresh stakes, carefully selected and chemically treated (Leihner, 1979), produce the best results; proper soil preparation-harrowing, waiting 2 weeks, then listing or ridging would eliminate two flushes of weeds (Viegas, 1976); planting method - horizontal planting results in slower sprouting of stems, which in turn results in more weed competition (Silva 1971b; Ribeiro Filho, 1966); variety, especially growth characteristics (Doll and Piedrahita, 1976); spacing - closer planting shades out weeds earlier (Conceição, 1975); weed species -some species are particularly difficult to control (Ribeiro Filho, 1966); weedseed in soil-good previous crop management prevents weed from going to seed and therefore reduces weed populations (Ribeiro Filho, 1966); and shading by cassava -3-4 months after being planted, the cassava produces shade that inhibits weed germination and growth (Silva 1971b; Doll and Piedrahita, 1976).

Weed control in cassava is traditionally done by hand with a hoe. EMBRAPA/EMBRATER (1976) for Ceara state in Brazil recommended making the first two weedings with an animal or tractor-drawn cultivator, returning with a hoe between plants in the rows. Silva (1979) suggested mechanizing weed control whenever possible, and Delgado and Quevedo (1977) indicated that furrowing and listing with a cultivator is advisable at about 2-3 months after planting because this operation not only controls weeds but improves drainage and facilitates harvesting. Earlier, Ribeiro Filho (1966) had recommended listing during the second and third cultivation but had said that thereafter weeds should be controlled only by hoeing because too much damage is done to the cassava plants by the cultivator.

The use of herbicides in cassava is quite new, but in recent years some excellent work has been done, especially in Latin America. Diaz and Arismendi (1973) in Venezuela obtained the highest root yields with Fluometuron (Cotoran) at 3 kg/ha and Ametrina (gexapax) at 2-3 gk/ha in a sandy loam soil; however Coelho and Correa (1971) in a heavy oxisol in Sete Lagoas, Brazil, found some phytotoxicity with Fluometuron during early development of the plant. Cunha $et$ $al$ (1975) in latosolic soils of Cruz das Almas, Bahia, Brazil, found Diuron (Karmex) to be selective. On the other hand, Moody (1972) observed 84 and 62% yield reduction by using Diuron and Linuron (Afalon, Lorox) at 3 kg/ha on sandy clay loam soils in Ibadan, Nigeria.

Jennings (1970) reported that weed control was only necessary during the early growth of cassava and the use of chemicals

to control weeds in cassava is uncommon in Africa.  In Sierra
Leone, Godfrey-Sam-Aggrey and Bundu (1972) suggested 30-day in-
tervals between weedings; Godfrey-Sam-Aggrey (1978) studied the
effects of not weeding and of weeding by hand at 30-, 45-, 60-,
and 90-day intervals and found that time and frequency of weed-
ing were important in influencing root yield.  Delayed weed
control depressed root yield.  The critical period of competi-
tion was in the 45-day weedings interval.

Valles (1977) in Tarapoto, Peru, found the critical period
to be between 45 and 60 days and the best treatment to keep the
crop weed free during the entire growing cycle.  In most cassa-
va-growing areas herbicides are not available and are a consi-
derable expense, initially, to the farmer.  According to Montal-
do (1966) herbicides should be used if planting are of a commer-
cial size of 20 or more hectares.  In sandy soils extreme cau-
tion should be used in applying herbicides.  Work done at CIAT
(1975) showed that even at low doses, the herbicides leach
enough in sandy soils to damage or kill the cassava.  Ridging
appeared to exacerbate the problem.  Some cassava cultivars
have been shown to be more susceptible to herbicide toxicity
(CIAT, 1974).  In other soils Doll and Piedrahita (1976) found
that Diuron (Karmex) applied as a preemergence spray plus one
hand weeding about 60-75 days after planting gave the most eco-
nomic weed control under CIAT conditions of heavy clay vertisols.

There are a lot of selective herbicides; Doll and Piedra-
hita (1976) listed 18 herbicides highly selective and 12 mode-
rately selective.  Leihner (personal communication, 1979) found
Oxifluorfen to be moderately selective alone or in mixture with
Alachlor.  This new herbicide controls both broad leaf and gras-
ses in preemergence.  It can be used safely at dosages between
0.5 and 1.0 kg/ha a.i. CIAT (1976) recommended the mixture of
Diuron and Alachlor (Lazo) at different dosages, according with
soil texture (Table 1), Diuron to control broad leaves and A-
lachlor to control grasses.

TABLE 1.   DIFFERENT DOSAGES OF DIURON AND ALACHLOR MIX-
           TURE ACCORDING TO SOIL TEXTURE.


|                | Dosage          |   |                  |
|----------------|-----------------|---|------------------|
| Soil texture   | Diuron (kg/ha)  |   | Alachlor (1/ha)  |
| Clay           | 2.0             | + | 3.0              |
| Silt loam      | 1.5             | + | 2.5              |
| Clay loam      | 1.5             | + | 2.0              |
| Sandy          | 1.0             | + | 2.0              |

Leihner (1979) recommended the mizture of Linuron and Flu-
orodifen (Preforan) at 0.5 + 2.5 kg a.i./ha applied in preemer-
gence to cassava intercropped with dry beans (*Phaseolus vulga-
ris*).


IRRIGATION


According to Cock and Howeler (1978), there are few data
on the water requirements of cassava, critical periods when
water is essential, or the response to irrigation. Their ex-
perience with cassava, unfortunately not yet supported by data,
has suggested that cassava requires moist soil for sprouting
and establishment of a sand. If a drought cccurs after the
first 2 months of growth, the cassava plant virtually spots
growing.

Under these circumstances leaves fall off, and the plant
essentially becomes dormant, whereas other crops like corn,
beans, and rice would die. With the onset of rain, cassava
utilizes carbhonydrate reserves in stems and roots to produce
new leaves (Cours,1949). These observations suggest that cas-
sava is an extremely useful crop in tropical areas of uncer-
tain rainfall.

In low rainfall areas, Campos and Sena (1974) found that
irrigating cassava affects root distribution. Irrigated cas-
sava had 91-98.5% of its roots in the upper 10 cm of soil, but
the nonirrigated cassava had roots in the upper 10 cm of soil.

Muthukrishnan *et al* (1973) and Smith (1968) both reported
decreased yields for cassava when irrigation was applied more
frequently than once a week. Cock and Howeler (1978) speculat-
ed that too frequent irrigation leads to excessive top growth
and reduces yields of manu varieties. Hence, cassava appears
to be better adapted to low rainfall areas and soils with low
waterholding capacity. Cassava, like most other crops, will
not tolerate excess water; yields are seriously reduced by poor
drainage. Menezes (1958) came to the conclusion that cassava
actually has the highest moisture requirements at 4-6 months
after planting.

Smith (1968) found that increased irrigation results in
lower starch content of harvested cassava - a finding that may
explain why many cassava growers try to harvest at the end of
the dry season before the rainy season provides enough moisture
to encourage a new flush of vegetative growth that uses starch
reserves in the roots and stems. For Bahia, Brazil, Conceiçao
(1975) recommended the application of about 35 mm of water
every 18 days during periods of little or no rainfall. In ad-
dition it was suggested that irrigation just prior to harvest

moistens heavy soil enough to facilitate harvesting. Shanmuga-
velu *et al* (1973) reported from India that irrigated cassava
nearly always outyields nonirrigated plantings. Best results
were obtained when cassava was irrigated every 8 days.

When reporting about irrigation, many researchers do not
include enough information about soil type (moisture holding
capacity) and climatic conditions, which are extremely import-
ant for decisions on whether a crop needs irrigation. In ad-
dition, the spacing, age, and vigour of the crop influence its
needs.

Celis and Toro (1974a, b) indicated that lack of moisture
causes serious losses in sprouting if the deficiency occurs
during the first 20 days after planting. A severe drought when
plants are very small may also cause plant losses. Consequent-
ly, the soil should be irrigated to field capacity when mois-
ture is lacking. If there has been no rain for at least 4
days during planting and irrigation is not feasible, planting
should be suspended unit the next rain.


PRUNING


Some methoda of planting such as horizontal often result
in three to five main sprouts that compete for space during
the development of the cassava plant. For this reason, EMBRAPA
(1975) for Amazonas, Brazil, recommended thinning sprouts to
two per plant after sprouting of the stakes. This is normally
done during the first weeding. Santos *et al* (1972) stated
that later pruning should not be done until the plants are a
year old and then only when propagation material is needed or
when the crop is attacked by other pests. In the latter case
the pruned portions should be removed from the field and burn-
ed.

EMBRAPA/EMBRATER (1976) also recommended that for the
state of Ceara, Brazil, pruning be done only for problems with
pests or for propagation material. In the latter case, branch-
es should only be pruned when the crop is dormant, which in
this area is January-March.

Some Colombian farmers commonly remove the suckers, vigor-
ous shoots that arise from the bases of the main stem usually
after the basic plant structure has been well established.
CIAT (1976) reported that suckers are useful to a plant only
at low populations or with low vigour types; otherwise, they
are inefficient and reduce yields. For this reason removing
the suckers is probably a beneficial practice for some culti-
vars.

Enyi (1972) reported from Africa that singleshoot plants outyielded multishoot plants, the difference increasing with a decrease in spacing distance. The single-shoot system and certain spacings were recommended for specific cultivars. The removal of the extra shoots should be carried out soon after the plant's emergence. Chan (1970), however, reported that pruning the plant to one stem led to a reduction in the root yield, and Shanmugham and Srinivasan (1973), studying the effect of single shoots and multishoots, found that two shoots outyielded the single-shoot and multishoot plants.

In 1977, Correa recommended against pruning until harvest because of the possibility of spreading bacterial blight and virus diseases. It was found that pruning at 6, 9, and 12 months limited yield by 43, 44, and 53% respectively. There was no effect after 15 months. Lozano *et al* (1978) found that pruning plants about 25 cm above ground and leaving the roots in the ground and leaving the roots in the ground for up to 20 days before harvesting actually decreased postharvest root deterioration from 100% to less than 20% depending on the variety. Tan and Bertrand (1972) stated that, as soon as stakes have sprouted new stems, many growers choose to maintain one stem per plant. Whether one chooses the single- or double-shoot system is of special importance in areas where cassava leaves are harvested periodically for human and livestock consumption; however, the choice at present is based more on tradition than on scientific research.

CROP ROTATION

Usually cassava is the last crop to be planted in a rotation program because of its exceptional ability to extract nutrients from the soil. Cassava extracts more nutrients from the soil than most other tropical crops at least in respect to phosphorus, potassium and magnesium, (Howeler, 1978). For this reason it is often advisable to leave land fallow or to rotate crops following the second or third consecutive cassava harvest, especially in medium to poor soils. If another crop must be planted immediately after cassava, fertilization with chemicals or manure should be considered.

Okigbo (1978) reported that in fields left fallow in east Africa, several different crops are commonly planted such as maize and beans, sweet potatores, bananas, yams, or sugarcane, which are in turn followed by cassava. Albuquerque (1969) indicated that in poor soils in Brazil the most recommended rotation for cassava is with legumes especially *Cannavalia ensiforme, Cajanus indicus,* and *Arachis hypogaea.* Sasidhar and Sadanandan (1976) found that growing cassava after cowpeas on a red loam acid soil (pH 5.8) was more profitable than any

other sequences involving cassava. Normanha (1971) noted that crop rotation is very important, cassava being a good crop to follow such crops as cotton maize, rice, sorghum, peanuts, soybeans, and beans. Rotation is especially advisable following years of cotton cultivation because of the expected phosphate residues in the soil. Control of cotton insects should also benefit cassava as would any crop residues (O.M.) in the soil. Correa (1977c) recommended beginning a rotation program as soon as cassava yields begin to decline and using soybeans or any legume normally grown in the area. In Sao Paulo state, good results were obtained in cases where the legume *Stizolobium* sp. was planted, cut, and plowed under as a green manure following every two cycles of cassava. Castro (1979) recommended, as a soil management practice, rotation of crops as a means to maintain soil fertility and to avoid the incidence of pest problems. Lozano and Terry (1978) recommended rotating cassava with corn or sorghum or fallowing land for 6 months when root rot levels are higher than 3% due to *Phytophtora drechsleri*. This practice should reduce the inoculum population enough so that cassava can be grown again.

Although cassava is noted for its ability to yield well on acid, infertile soils, it extracts 100 kg of $K_2O$ for each 25 t of roots. Grown continuously without adequate fertilization, the cassava may exhaust the potassium reserves in the soil (Howeler 1978).

HARVESTING

Harvesting is extremely laborious when performed manually; it is also costly. Diaz *et al* (1974) reported that harvesting in Colombia represents more than 30% of the production costs. The manual methods that are usually employed are rudimentary and inefficient, although Toro and Jaramillo (1974) have described several manual and semimechanical devices that facilitates harvesting, improve efficiency, and thus reduce costs and fatigue. In 1970, Beeny indicated that vibration would facilitate cassava harvesting, and according to Briceño and Larson (1972), vibration combined with pulling or lifting is an efficient means of harvesting. When pulling alone is used, the stem may break and the roots remain buried. Briceño and Larson developed a blade lifter that is attached to the tractor by a three-point hitch. The tool requires 80 h.p. at the power take-off and gives a field capacity of 0.29 ha/day. Bates (1957) suggested that a modified potato harvester could do the job in cassava.

Hossne (1971) indicated that a couple of resistant and modified bands inclined like those used for sugar beets could be used for harvesting. Leihner (1978) evaluated two cassava harvesting machines in a friable clay-loam ultisol at CIAT-Quili-

233

chao experiment station using three different varieties at 5000, 10,000 and 20,000 plants/ha planted vertically on the flat. Plots of varieties MMex-11, CMC-84, MCol-22, which are classified as difficult, intermediate, and easy for manual harvesting, were harvested mechanically and by hand. The machines used were a Richter harvester manufactured by Richter Engineering Ltd, Boonah, Australia, and a CIAT lifter. The results indicated that both mechanical methods left fewer roots in the soil than did manual harvesting of the difficult-to-harvest variety, and the difference in performance of the two machines was small. Both harvesters cut down time and effort involved. Kemp (1978) with the same machines in the same field with the same varieties found that both harvesters proved to be positive alternatives to the drudgery of manual harvesting. For mechanical harvesting, Cock *et al* (1978) recommended a compact or clumped tupe of rooting that can be obtained by selection of the right variety and by use of stakes that have been cut straight across and planted vertically on ridges.

Wijerwardene and Garman (personal communication) reported the performance of four mechanical cassava harvesters working in a wet clay soil with 10,000 plants/ha planted on the flat. Cassava tops were manually cut and removed before the trial. The results were: Ransomes, a European root-crops harvester with a fixed blade and chain elevator performed well with good separation of dirt and roots with a rate of operation of 4.5 hours/ha; A.P.I. operating on the vibrating blade principle with oscillatory elevator was a failure in the clay soil, although it had worked satisfactorily in dry, light soils of Ghana; Alpha-Record, an oscillatory blade and lifter design, also demonstrated the unsuitability of oscillating mechanisms on wet clay soils; and CIAT, a simple blade with lifter designed and developed at CIAT by agricultural engineer. Alfonso Diaz, and built at IITA, performed the best of all. The soil and cassava roots flowed well over the blade, the lifting mechanism leaving the roots well loosened and exposed (about 50% out of the soil). The rate of operation was 3.5 hours/ha.

This trial was valuable in that it pointed out the right way to go for fully mechanized harvesting: a simple lifting blade, like the CIAT tool, 2 m wide for two rows, followed by a two-stage, endless-belt elevator to separate soil and dirt and deposit the roots into a trailer traveling alongside.

With cassava production increasing, many machinery manufacturers are interested in developing new harvesters; for instance, G.M.D. of Reims, France, has released a cassava digger-type mounted for linkage on rhw hydraulic lift of the tractor.

No matter what harvesting method is used, some general considerations are aplicable; if planting is done on ridges or beds, harvesting tends to be easier than on flat ground;

in loose or sandy soils, harvesting is easier than in clay or
heavy soils; and in any type of soil, harvesting is easier
when the soil is wet than when it is dry.


CONCLUSIONS


One cannot generalize about cultural practices for grow-
ing cassava in any country, although there are some agronomic
practices that have proced to be effective everywhere. Each
production area has soil and climatic factors that are specific
to the locality, and the responses of individual cassava var-
ieties differ from one place to another. Whenever an appropri-
ate technology is needed for a specific cassava-growing region,
it must be developed by national research organizations. In
many cases, little adjustments to recommended technological
packages are enough for good cassava production.

IITA and CIAT have been engaged in cassava research for
the last decade. Working in a multidisciplinary team approach,
they have obtained good results from applied research.

Using improved cassava technology based on low inputs,
CIAT, after 5 years of regional trials with consistent results,
has indicated that it is possible for farmers to double cassa-
va yields with their own local varieties by following the re-
commended technological package. The package comprises two
parts: one for areas where cassava is traditionally grown and
the other for areas of subutilized ultisols and oxisols, which
represent about 1.76 billion hectares of the world.


Technology for traditional cassava-growing areas:

(1) good soil preparation; (2) selection and treatment
of planting material (Lozano *et al*, 1977); (3) planting at the
beginning of the rainy season; (4) planting 20 cm stakes in
vertical position with buds facing up; (5) planting on ridges
where soils are heavy and rainfall is more tha 1200 mm/year
(Loano and Terry, 1978); and (6) planting 10,000 stakes per
hectare unless local research indicates a different population.


Technology for ultisols and oxisols:

(1) all steps described for traditional cassava-growing
areas and (2) fertilization (Table 2). The plan in Table 2
was derived from 9 years research at ICA-CIAT, Carimagua sta-
tion. The plan contemplates planting cassava in the same field
year after year. Dolomitic limestone must be incorporated, and
the other products can be applied in bands side by side at the

time of planting.  For the treatment of stakes, 20 g of zinc
sulphate per litre of water should be added to the fungicide
and the stakes immersed in the mixture for 15 minutes.  For
the Colombian oxisols, planting time should be between 15 Sep-
tember and 20 October so that the incidence of pests and dis-
eases is minimized (Lozano and Terry, 1978).

TABLE 2.   FERTILIZATION PLAN FOR CONTINUOUS CASSAVA
           PRODUCTION IN ULTISOLS AND OXISOLS (Howeler,
           personal communication, 1979).

| | Dosage (kg/ha)[a] | | | |
| Fertilizer | 1st year | 2nd year | 3rd year | 4th[b] year |
|---|---|---|---|---|
| 10-20-20 | 1000 | 750 | 500 | 1000 |
| Dolomitic limestone | 1000 | -- | -- | 1000 |
| Sulphur | 10 | 10 | 10 | 10 |
| Zinc | 5 | 5 | 5 | 5 |

a    When cassava is planted only 1 year, fertilizer
     should be split accordingly.

b    After the 3rd year, the plant starts over again.


    To tale more advatange of future information on cassava
production research, investigators need detailed descriptions
of soil, climate, the objectives of research, materials and
methods used, data collected and statistical evaluation. With
these factors, they can extrapolate results.

    Because the cassava dry matter content is highly correlat-
ed with its starch content and because starch is the most im-
portant product of cassava anyway, it is of great importance
to indicate this information.  Also, researchers must know the
number of days to harvest to make real comparisons on yield
because the dry matter accumulation per hectare per day is one
of the best indicators of the yield potential of any variety.
Experiments must be repeated at least 3 years in the same lo-
cation before conclusive results and recommendations can be
arrived at.

    More research is needed in the area of cassava forage pro-
duction and utilization because the cassava tops represent 40-
50% of the total plant.  More is needed also in the area of

236

storage and production of cassava stakes, especially in areas
of extreme climatic conditions and severe pest and disease
stress.

Finally, one may conclude with Normanha (1975) that the
most important cultural practices for cassava root production
are selection of healthy and mature stakes; planting time; and
good weed control. These simple practices can be considered
universal in cassava production because they apply everywhere.

# INFLUENCE OF PERIOD AND CONDITIONS OF STORAGE ON

# GROWTH AND YIELD OF CASSAVA

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ABSTRACTS


Cassava planting often takes place during the rainy season, but harvesting is carried out during the dry season, thus there May be considerable periods of time between harvest and subsequent planitng. As a result, storage of planting material for up to several months is necessary.

A great number of storage methods are used to preserve the stakes and protect them against physical damage, dehydration, and extreme temperatures. Chemical treatment is highly efficient in preventing pathogenic infestation, which is an important factor causing germination losses. In adequate storage conditions, chemically treated stakes can be preserved for 6 months under CIAT's conditions. Although there may be no losses in final stand, vigour of planting material is reduced and the number of thick roots tends to decrease. This translates into lower yields coming from stored stakes.

Practices that could reduce the effect of storage on the initial vigour and formation of thick roots could contribute to minimizing yield losses.

INTRODUCTION


Cassava propagation material is susceptible to adverse climatic conditions and to pests and diseases. Thus, when exposed to the sun after cutting, it can loose viability in a short time due to dehydration. But excessive moisture may cause bud sprouting. Pathogens and pests are also common causes for bad sprouting after planting. Better sprouting is obtained with stakes harvested shortly before planting if compar-

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ed to stored stakes (Correa 1970, 1977a, b; Silva 1970). Besides, there are varietal differences in the sprouting vigour of stakes, which are emphasized with extension of the storage period (CIAT, 1977; Lozano *et al*, 1977).


STORAGE PERIOD AND CONDITIONS


When storage is necessary, it is advisable to protect stakes against external agents and dehydration by using chemical products. Another possibility would be to inhibit early sprouting of buds and stimulate then when necessary. Theoretically this is possible and studies are being done in this field using hormones (CIAT, 1978). However, hormone use is complex because slight mistakes in dosages can produce contrary effects, amking application under farm conditions difficult.

The literature shows discrepancies in relation to the maximum possible period of stake storage. If no fixed period of time is given, expressions like "reasonable period", "several months", or "some time", are mentioned. Lozano *et al* (1977) observed good sprouting after a storage period of 30 days, reference has also been made to 8 weeks (Krochmal, 1969), to periods longer than 30 days (EMBRAPA, 1976), and to a possible period of from 3 to 5 months (Mendes, 1949).

The different opinions among researchers in relation to adequate storage conditions are due, at least partially, to the different environments in which they work, as well as to methodological and varietal difference. According to Kiernowski (1950) cassava varieties have different storage performance depending on the conservation method used. Lozano *et al* (1977) mentioned that there are sprouting differences between varieties that are stressed by extension of the storage period.

However, in spite of the different points of view, some aspects are common to all investigations.

1. Stake storage. Storage should be avoided, if possible. Silva (1970) and Correa and Vieira Neto (1978) mention a trial in which a high percentage of sprouting was obtained with stakes planted shortly after harvest (100%) as compared to stakes kept vertically under tree shade (70%), in the field in a horizontal position (50%), and in a cold room used for seed potatoes (20%).

2. Stake position and storage environment. Horizontal and vertical positions are equally recommended and produce good rsults when storage is carried out in cool and shady environments avoiding direct sun, hor or cold winds, and dehydration.

3. Position. When stakes are stored vertically, the buds should be facing upt to obtain better sprouting.

4. Stake length. Long stakes are better preserved than short ones (Castellar and Mogollon, 1972; CIAT 1973, 1974).

5. Stake quality. Stakes should have the right maturity and come from healthy cassava plantations. Material attacked by pathogens and/or pests should be avoided. In areas subject to frosts, stakes should not be stored above ground under field conditions.

Lozano *et al* (1977) suggest the use of varieties tolerant to storage because they usually have a better sprouting potential. Stephens (1965) recommends stakes with the right maturity. These should not be wet when stored nor should they be exposed later to humidity.

CHEMICAL TREATMENT

Stake spraying with a solution of Bordeaux mixture at 0.25% (Normanha,1946) or at 0.50% (Normanha and Pereira, 1950) before storage prevents fungal attack. Mercury products used before storage also help to obtain good conservation (Viegas, 1976). For CIAT (1974), stake treatment with the commercial product CIPC delayed bud sprouting 4 weeks, and according to CIAT (1979) the use of sodium alginate prevent dehydration during storage.

Lozano *et al* (1977) mentioned that fungicide treatment before storage results in more than 90% sprouting after a month and a yield increase of more than 25%. A mixture, insecticide, and/or miticide should be used. Among other products, a mixture of Orthocide and Bavistin (BCM and Captan) at a rate of 3000 ppm each is recommended. The advantages are their disinfective and protective action, the increase of conservation time, and the speed of sprouting and rooting.

In a 4-week conservation test using a variety with high sprouting potential (MCol 946), and another with low potential (M Col 803), and previous stake treatment with a mixture of BCM and Captam, the following yields were obtained: MCol 946 treated 28.0 t/ha, untreated 18.0 t/ha; MCol 803 treated 25 t/ha, untreated 0 t/ha (CIAT, 1977).

# YIELD TRIALS

To evaluate this technology in longer storage periods under different conditions, a trial was carried out using planting material of the good sprouting variety CMC 76. Storage conditions were a dry room on a wooden base (horizontally) or placed on the ground (vertically, with buds facing up) under a bamboo canopy, and covered with plastic in earth soils. The material was previously immersed in a solution of BCM and Captam (Bavistin and Orthoxide) at 3000 ppm each.

When storage periods ended, the 1-m long bars were cut into 20 cm stakes and treated with a mixture of fungicides, insecticides, and micronutrients, in a preplanting treatment, and were ridge planted at 1.0 x 1.0 m. The field was previously irrigated to ensure good humidity conditions.

## Sprouting

The final sprouting percentage as well as the sprouting rate (number of plants/day/plot) was determined. In adequate storage conditions (dry room or bamboo shade), the sprouting rate was greater in stored material than in fresh material, independent of storage period. Even with inadequate storage conditions (earth silos, 1.0 m or 20 cm stakes) the srpouting rate with 30 days of storage was higher than the rate obtained with fresh material.

The final sprouting percentage was almost not affected by storage duration under adequate storage conditions, reaching 95-100% in all periods. On the other hand, the final sprouting percentage was drastically reduced with longer storage periods, when conditions were inadequate.

## CASSAVA YIELD

Both duration and condition of storage affected fresh root yield (Tables 1 and 2). Yield decreased as a consequence of longer periods of storage under any conditions, but the decrease was more drastic under inadequate conservation conditions. The effect of length and storage conditions as well as their interaction were highly significant (P = 0.001). The significant interaction effect indicated that with longer storage periods, the conditions under which planting material is stored become more critical. Fresh root yields proved that the best storage condition in this trial was under a bamboo canopy with 1 m stakes stored vertically and buds facing up. Rooting and partial sprouting did not seriously affect conservation or

242

TABLE 1.   CASSAVA FRESH ROOT YIELD AS INFLUENCED BY CONDITION
           AND TIME OF STORAGE OF PLANTING MATERIAL (CIAT,1979)

| Condition of storage | Time of storage (days) | Stand at harvest (%) | Root Yield (t/ha) |
|---|---|---|---|
| Dry room, 1 m stake, vertical | 0 | 100 | 35.5 |
| | 30 | 100 | 29.7 |
| | 60 | 98 | 26.9 |
| | 90 | 98 | 24.0 |
| Open air, shade, wooden base, 1 m stake, horizontal | 0 | 100 | 35.5 |
| | 30 | 100 | 24.5 |
| | 60 | 100 | 24.0 |
| | 90 | 94 | 25.5 |
| Open air, shade, 1 m stake, vertical, on soil | 0 | 100 | 35.5 |
| | 30 | 100 | 31.9 |
| | 60 | 100 | 27.8 |
| | 90 | 96 | 23.9 |
| Earth silo, 1 m stake, plastic wrap, horizontal | 0 | 100 | 35.5 |
| | 30 | 73 | 20.3 |
| | 60 | 65 | 19.6 |
| | 90 | 0 | 0.0 |
| Earth silo, 20 cm stake, plastic wrap, horizontal | 0 | 100 | 35.5 |
| | 30 | 96 | 31.5 |
| | 60 | 79 | 21.8 |
| | 90 | 0 | 0.0 |
| C.V. % | | 8.7 | 16.0 |
| SD | | 7.26 | 3.9 |

TABLE 2. EFFECT OF STORAGE DURATION OF PLANTING MATERIAL ON
ROOT CHARACTERISTICS OF CASSAVA PLANTS HARVESTED 11
MONTHS AFTER PLANTING. VARIETY CMC-76, CHEMICAL
TREATMENT: CMC AND CAPTAN AT A RATE OF 3000 PPM EACH.
MEANS OF FIVE STORAGE CONDITIONS (CIAT, 1979).

| Storage duration (days) | No. roots per plant | No. marketable roots per plant | Mean root length (cm) | Mean root perimeter (cm) |
|---|---|---|---|---|
| 0 | 12.2a | 7.5a | 26.3 | 19.8ab |
| 30 | 11.5a | 6.2ab | 26.1a | 19.3b |
| 60 | 9.4b | 5.1b | 27.2a | 21.1a |
| 90 | 10.7ab | 5.8b | 26.7a | 21.0a |

a    Figures followed by the same letter are not significantly
     different at the 5% level (Duncan's Multiple Range Test).

establishment of the crop. On the other hand, stakes (1.0m or
20 cm) wrapped in plastic and buried in silos of about 80 cm
depth produced excessive humidity and suffered premature sprout-
ing. This caused great reductions in sprouting after planting.

Under these conditions, the difference in yield due to
different storage periods was explained by final stand percent-
age ($r^2 = 0.90$***). In contrast, under adequate conditions
(under bamboo canopy, on a wooden base, or on the soil) a great
part of the variation of fresh root yield due to the different
storage periods could not be explained by the final stand per-
centage ($r^2 = 0.42^{n.s.}$). This showed that besides plant popula-
tion, other factors related to duration and condition of stor-
age influenced root yields (Fig.1).

Size and number of roots

Plants from stored stakes produced less total and commer-
cial roots per plant, than those originated from fresh material.
Plants with less roots had a tendency to compensate for lower
root numbers by increasing root size, however, this was not
enough to balance production. The decrease in number of roots
per plant was significant, and partially explains the reduction
in yield ($r^2 = 0.80$****) even under adequate storage conditions.

244
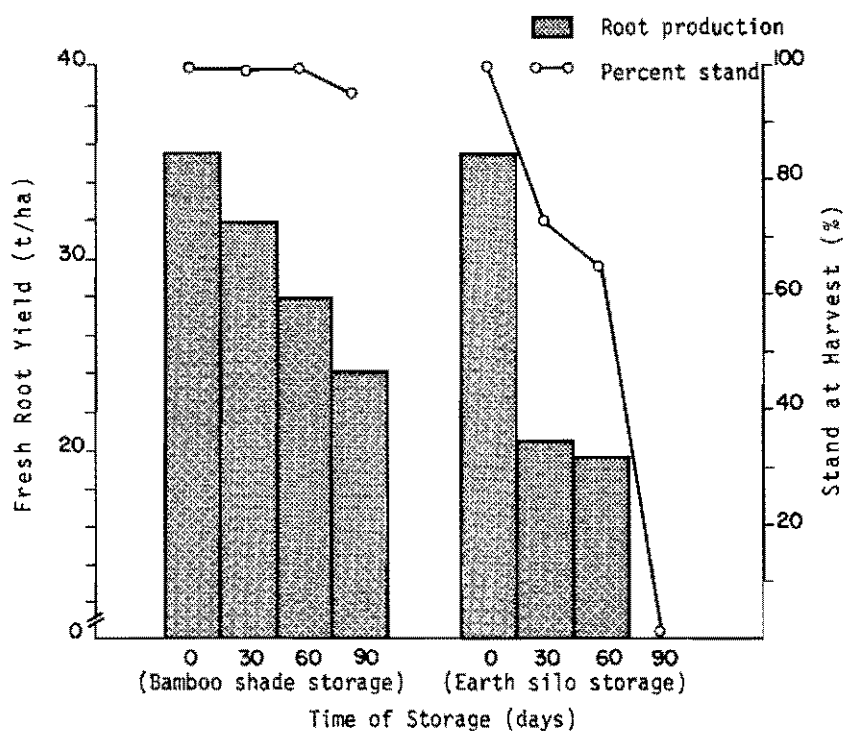
FIGURE 1. PERCENT STAND AT HARVEST AND CASSAVA FRESH ROOT YIELD AS INFLUENCED BY TIME OF STORAGE UNDER TWO DIFFERENT STORAGE CONDITIONS AT CIAT/PALMIRA, 1979.

245

TABLE 3. EFFECT OF STORAGE DURATION ON GROWTH PARAMETERS OF STAKES OF VARIETY CMC-40, KEPT UNDER A BAMBOO CANOPY AND TREATED WITH BCM AND CAPTAN (3000 PPM EACH).

| Storage duration (days) | Sprouting 31 DAP[a] (%) | Sprouting rate (plants/day/plot) | Plant height 45 DAP (cm) | Leaf size 60 DAP (cm) | Average No. stems/plant 60 DAP | LTR[b] 76 DAP (%) |
|---|---|---|---|---|---|---|
| 0 | 100a[c] | 1.73a | 26a | 278ab | 2.66a | 23a |
| 60 | 100a | 1.83a | 27a | 282ab | 2.73a | 22a |
| 120 | 100a | 1.59ab | 23b | 253b | 2.36b | 28a |
| 180 | 98b | 1.40b | 25ab | 296a | 2.23b | 25a |

[a]DAP = DAYS AFTER PLANTING

[b]LIGHT TRANSMISSION RATIO

[c]FIGURES FOLLOWED BY THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT AT THE 5% LEVEL (DUNCAN'S MULTIPLE RANGE TEST).

## INITIAL GROWTH AND STORAGE DURATION

In a recently planted trial with stakes stored for up to 180 days, the influence of storage duration on initial growth was studied in greater detail. Because the material was treated with fungicides and was adequately stored (under bamboo canopy, vertically, on the soil) no effect of the storage period on final sprouting percentage was observed, sprouting 1 month after planting being almost 100% even with 4 and 6 months of storage. However, there was a reaction in relation to other parameters (Table 3). A lower germination rate with storage periods above 60 days and shorter plants could be due to less vigour of the stored material. Also, smaller leaves (with the exception of 180 days storage) and the significant reduction of number of stems per plant as well as a higher light transmission ratio (LTR) may be an expression of this reduced vigour. It is interesting to note that there was no significant decrease in growth parameters with 60 days of storage.

Final harvest data should indicate how the reduced germination rate and slower initial growth, will affect the development of the root system and the formation of thick roots. Identification of factors that make plants from stored stakes less efficient in terms of early growth and thick root formation could allow the development of even better practices to preserve vigour of planting material and minimize yield losses.

## CONCLUSIONS

The results and observations obtained up to the present are:

1. The most important factor in cassava yield decrease due to stake storage is reduction of sprouting produced by pathogenic infestation or unfavourable environmental conditions during storage. Poor sprouting results in a deficient population at harvest.

2. Under adequate storage conditions and chemical treatment, cassava stakes can be preserved for several months, keeping high sprouting percentages.

3. In tropical climates, storage of planting material under tree shade, eliminates the need for special and expensive facilities.

4. Storage conditions will be more critical the longer the duration of storage.

5. Whe sprouting potential of stakes is preserved by chemical treatment and adequate storage conditions, yield reduction can no longer be explained by final stand percentage. In this case, it seems that other factors affecting top and root growth are responsible for yield variations.

6. Identification of these factors will allow the identification of management practices for stored planting material, not only to ensure a high sprouting percentage but also to minimize yield losses.

# MINERAL NUTRITION AND FERTILIZATION OF CASSAVA

## - A REVIEW OF RECENT RESEARCH -

Reinhardt H. Howeler*

## INTRODUCTION

Throughout the tropics and subtropics cassava is grown on a wide range of soils, the main limitation being that the soil has to be reasonably well drained. Cassava will not tolerate excess water and does not survive more than a few days of water logging. Table 1 shows that in tropical Latin America cassava is grown mainly in very acid and infertile Ultisols and Oxisols, as well as in Alfisols, principally in N.E. Brazil. In Africa and Asia these are also the predominant cassava soils. Of secundary importance are Entisols and Inceptisols. While cassava grows well on Mollisols and the better-drained Vertisols, these highly fertile soils are generally used for higher-value crops such as sugarcane, sorghum, cotton, maize and soybeans. Cassava is generally grown on the poorer soils and in areas with low or uncertain rainfall, because the crop still produces under these unfavorable conditions while other crops would perish. In tropical Latin America over 50% of cassava is grown on Ultisols, Oxisols and Inceptisols, which are all characterized by extreme acidity and low levels of available N, P and K. Still, fertilizers or lime are seldom applied to the crop since farmers generally belief that the crop does not need good fertility and does not respond to fertilization. However, numerous trials conducted by FAO throughout the world between 1961 and 1977 (FAO, 1980) indicate that cassava is as responsive to fertilizer applications as most other crops that traditionally are fertilized (Table 2), and that this practice is highly economical, as indicated by the high value/cost ratio. This in general, cassava is traditionally grown without fertilization on very poor soils, while recent investigations show that on these soils adequate fertilization is essential for high and sustainable yields.

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TABLE 1. SOILS ON WHICH CASSAVA IS PRODUCED IN LATIN AMERICA AND THEIR PRINCIPAL
NUTRITIONAL CONSTRAINTS.

| | Soil distribution* % | Cassava production # % | Constraints | | | |
|---|---|---|---|---|---|---|
| | | | Acidity | N | P | K |
| Ultisols | 19.1 | 27.0 | ++ | + | ++ | + |
| Alfisols | 12.2 | 23.2 | - | - | - | - |
| Oxisols | 45.3 | 19.0 | ++ | + | ++ | ++ |
| Entisols | 8.6 | 13.4 | - | ++ | + | + |
| Inceptisols | 8.2 | 6.9 | ++ | + | ++ | + |
| Mollisols | 3.9 | 5.5 | - | - | - | - |
| Vertisols | 0.7 | 4.2 | - | - | - | - |
| Aridisols | 1.9 | 0.4 | - | - | - | - |

* Distribution of soils in tropical Latin America (Sanchez 1976)

# Agroecological Studies Unit - CIAT, 1983

TABLE 2.   THE AVERAGE HIGHEST PERCENT YIELD INCREASE DUE TO
           FERTILIZATION AND VALUE/COST RATIO (VCR) FOR CASSAVA
           AS COMPARED TO OTHER MAJOR CROPS IN VARIOUS COUNTRIES
           (FAO, 1980).

| Country | Crop | No. trials | Average best | |
|---------|------|------------|-----------|-----|
| | | | % Response | VCR |
| Brazil | Cassava | 66 | 111.6 | 5.63 |
| '70-76 | Maize | 510 | 83.1 | 2.74 |
| | Cotton | 490 | 84.2 | 3.73 |
| | Beans | 391 | 91.1 | 4.89 |
| | Rice | 385 | 76.6 | 4.81 |
| | Soybean | 124 | 102.4 | 2.38 |
| | Sugarcane | 105 | 66.6 | 3.64 |
| Colombia | Cassava | 16 | 124.5 | 5.89 |
| '62-70 | Maize | 102 | 95.2 | 6.38 |
| | Beans | 47 | 67.2 | 5.96 |
| | Forage | 41 | 153.6 | 1.68 |
| | Potatoes | 33 | 266.4 | 11.40 |
| | Wheat | 15 | 72.8 | 4.43 |
| Ghana | Cassava | 134 | 71.0 | 19.90 |
| | Maize | 775 | 121.2 | 9.59 |
| | Groundnuts | 134 | 52.1 | 18.70 |
| | Cotton | 92 | 82.1 | 18.31 |
| | Cowpeas | 61 | 65.1 | 15.90 |
| Indonesia | Cassava | 56 | 176.4 | 4.19 |
| '69-76 | Rice | 378 | 62.6 | 3.12 |
| | Sorghum | 312 | 217.0 | 2.46 |
| | Groundnut | 135 | 60.0 | 4.88 |
| | Soybean | 117 | 59.9 | 3.12 |
| Nigeria | Cassava | 28 | 53.5 | 11.26 |
| | Maize | 478 | 64.1 | 5.12 |
| | Yams | 348 | 43.5 | 22.60 |
| | Rice | 277 | 41.8 | 13.78 |

Nutrient Extraction and its Effect on Soil Fertility

Farmers know that cassava extracts large amounts of nutri-
ents from the soil and for that reason often plant cassava as
the last crop in a rotation before turning the plot back to
bush fallow.  Due to its high yield potential cassava indeed
extracts large amounts of nutrients from the soil.  Kanapathy
(1974) showed that a cassava crop of 18.6 t/ha extracted more
N, P, K and Mg than crops like oilpalm, rubber or corn.  Prevott
(1958) calculated the nutrient extraction in the harvested pro-
duct of 17 tropical crops (Table 3) and showed that cassava ex-
tracted the largest amounts of K and P, and only rubber extract-
ed more N on a per hectare basis.  Similar data were reported
by Amarasiri and Perera (1975), as shown in Table 4.

Thus, on a per crop or per hectare basis cassava removes
more nutrients from the soil than most other crops and this can
have serious repercusions on soil fertility.  However, when nu-
trient extraction is calculated on the basis of per ton dry mat-
ter harvested, cassava extracts less N and P than potatoes,
maize, rice or bean, and less K than potatoes or beans (Table 5).
Thus the large nutrient removal is clearly related to its high
yield potential.  Reviewing the literature, Howeler (1981) re-
ported a large variation in nutrient extraction data due to dif-
ferences in soil fertility conditions, fertilizers applied, var-
ieties used and the age of plants at harves.  It was calculated
that on the average, cassava extracts per ton of fresh roots
produced about 2.3 Kg of N, 0.5 Kg P, 4.2 Kg K, 0.6 Kg Ca and
0.3 Kg Mg in the root harvest, and 4.9 Kg N, a.a Kg P, 5.8 Kg
K, 1.8 Kg Ca and 0.8 Kg Mg in the whole plant.  Thus in the
root harvest, cassava extracts large amounts of K, followed by
N and relatively little P, Ca and Mg.  Table 6 shows the dry
matter and nutrient distribution in fertilized and unfertilized
cassava in Carimagua.  While the plant absorbed more N than K
from the soil, the nutrient removal in the root harvest was
greater for K than N.  In case of unfertilized cassava nearly
60% of absorbed K was present in the roots while this was only
25% for N and 46% for P.  Thus, much of the absorbed N is re-
turned to the soil as fallen leaves or as tops after harvest.

The large extraction of K in each root harvest can lead
to K exhaustion of the soil.  Thus, den Doop (1937) reported
that in three consecutive cassava planting without applied K,
yields decreased from 15 t/ha in the first year to 4 t/ha in
the third year.  Similarly, Chan (1980) reported that in a long-
term fertility trial in Malaysia yields decreased from 32 to
20 t/ha in 9 consecutive cassava croppings without fertiliza-
tion (Fig.1); with application of 112 Kg N, 68 Kg P, and 156 Kg
K/ha yields actually increased from 30 to 54 t/ha in the ninth
crop.  The yield decline without fertilization was mainly due
to K exhaustion.  Similar results were obtained with six conse-
cutive cassava crops grown in CIAT-Quilichao with different le-

TABLE 3.   EXPORTATION (Kg/ha) OF NUTRIENTS AND RELATION
           K/N IN HARVESTS OF TROPICAL CROPS (PREVOTT,
           1953).

|                    | N   | P    | K   | K/N  |
|--------------------|-----|------|-----|------|
| Cassava            | 124 | 46.0 | 485 | 3.91 |
| Banana             | 56  | 3.5  | 161 | 2.88 |
| African oilpalm    | 39  | 6.2  | 85  | 2.18 |
| Pineapple          | 110 | 13.2 | 228 | 2.03 |
| Coconut palm       | 35  | 6.6  | 71  | 2.03 |
| Sugarcane          | 76  | 23.3 | 144 | 1.89 |
| Tobacco            | 28  | 3.1  | 35  | 1.25 |
| Sisal fiber        | 122 | 18.5 | 149 | 1.22 |
| Soybean            | 58  | 16.2 | 65  | 1.12 |
| Cocoa              | 19  | 4.4  | 21  | 1.1' |
| Virginia tobacco   | 88  | 4.4  | 86  | 0.98 |
| Coffee             | 32  | 2.6  | 30  | 0.94 |
| Rice               | 21  | 4.8  | 9   | 0.43 |
| Maize              | 103 | 16.7 | 85  | 0.82 |
| Thea               | 5   | 0.3  | 2   | 0.41 |
| Rubber             | 420 | 26.0 | 160 | 0.38 |
| Cotton             | 66  | 11.4 | 22  | 0.33 |

TABLE 4. YIELD AND NUTRIENT REMOVAL OF SEVERAL CROPS GROWN ON AN ALFISOL IN SRI LANKA (AMARASIRI AND PERERA, 1975).

| Crop and duration (days) | Plant part | t/ha yield | Nutrients removed (Kg/ha) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | N | P | K | Ca | Mg | S |
| Cassava 180 | Fresh roots total | 45 | 62 202 | 10 32 | 164 286 | 12 131 | 22 108 | 3 15 |
| Sweet potato 100 | Fresh tuber total | 15 | 31 89 | 6 17 | 51 187 | 10 44 | 4 26 | 3 14 |
| Rice 130 | Grain total | 5 | 58 100 | 12 18 | 10 151 | 2 27 | 7 23 | 3 9 |
| Sorghum 100 | Grain total | 4 | 68 101 | 8 13 | 16 108 | 3 17 | 6 14 | 2 5 |
| Maize 105 | Grain total | 4 | 64 118 | 7 11 | 13 155 | 2 32 | 2 25 | 6 13 |
| Cotton 150 | Seed cotton total | 1.9 | 40 77 | 6 14 | 7 68 | 6 34 | 5 21 | 2 19 |
| Cowpea 90 | Grain total | 1.5 | 50 60 | 4 5 | 19 36 | 3 11 | 2 6 | 2 4 |
| Groundnut 100 | Grain total | 1.8 | 88 101 | 5 6 | 12 34 | 1 12 | 3 8 | 2 4 |
| Soybean 90 | Grain total | 1.2 | 103 118 | 10 11 | 34 47 | 6 16 | 4 9 | 3 5 |

TABLE 5.    NUTRIENTS EXTRACTED BY VARIOUS CROPS PER TON OF DRY
            MATTER HARVESTED.

| | N | P | K | Total |
|---|---|---|---|---|
| | | | Kg | |
| Cassava (roots) | 6 | 1 | 11 | 18 |
| Potatoes (tubers) | 17 | 3 | 26 | 46 |
| Maize (grain) | 19 | 3 | 4 | 26 |
| Rice (grain) | 16 | 3 | 3 | 22 |
| Beans (grain) | 37 | 3 | 22 | 62 |

vels of NPK, applied either once before the first crop or an-
nually before every planting.  Figure 2 shows the change in re-
lative yield of selected treatments over time.  When fertiliz-
ers were applied only once with the first crop, its residual
effect slowly disappeared with time; P application in the ab-
sence of K actually had a negative effect after the third crop-
ping, because high yields in the first crops had exhausted the
soil K-supply.  However, with the annual application of rather
high levels of K it was possible to increase yields over time.
In the fourth cropping cassava yields were 23 t/ha without ap-
plied fertilizers compared with 63 t/ha with the annual appli-
cation of 200 Kg N, 175 Kg P and 250 Kg K/ha; nearly 60% of
this increase was due to K application.

    Figure 3 shows the change in available P and exchangeable
K contents of the soil.  The initial application of 87 and 175
Kg P/ha resulted in Bray II - extractable P levels of 22 and
42 ppm, respectively, compared with 7 ppm without applied P.
However,  without further P applications, the residual effect
nearly disappeared with the second crop, resulting in available
P levels of 2 to 7 ppm.  With the annual application of 87 and
175 Kg P/ha, available P levels in the soil increased every
year to levels of 42 and 89 ppm, respectively, after the sixth
crop.  However these high P levels do not contribute to increas-
ed yields, and after the first few years P applications could
have been reduced without affecting yields.  On the other hand,
Figure 3B shows that annual applications of about 125 Kg K/ha
were required to maintain the original K level of 0.2 me/100 gm
and a high yield of 41 t/ha in the 6th crop, compared with 19
t/ha without K application.  The annual application of 250 Kg
K/ha increased the soil K level to 0.46 me/100 gm, resulting

TABLE 6. DRY MATTER (DM) AND NUTRIENT DISTRIBUTION IN 12 MONTH OLD CASSAVA, cv. MVEN 77, GROWN WITHOUT AND WITH FERTILIZATION IN CARIMAGUA. PLANT POPULATION WAS 15.625/ha

| Unfertilized | t/ha DM | N | P | K | Ca | Mg | S | B | Cu | Fe | Mn | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tops | 5.11 | 69.1 | 7.4 | 33.6 | 37.4 | 16.2 | 8.2 | 0.07 | 0.03 | 0.45 | 0.33 | 0.26 |
| Roots | 10.75 | 30.3 | 7.5 | 54.9 | 5.4 | 6.5 | 3.3 | 0.08 | 0.02 | 0.38 | 0.02 | 0.10 |
| Fallen leaves | 1.55 | 23.7 | 1.5 | 4.0 | 24.7 | 4.0 | 2.5 | 0.04 | 0.01 | --- | 0.37 | 0.18 |
| Total | 17.41 | 123.1 | 16.4 | 92.5 | 67.5 | 26.7 | 14.0 | 0.19 | 0.06 | --- | 0.72 | 0.54 |
| **Fertilized** | | | | | | | | | | | | |
| Tops | 6.91 | 99.9 | 11.7 | 74.3 | 55.0 | 15.3 | 9.6 | 0.08 | 0.03 | 0.78 | 0.57 | 0.30 |
| Roots | 13.97 | 67.3 | 16.8 | 102.1 | 15.5 | 8.4 | 7.0 | 0.07 | 0.03 | 0.90 | 0.06 | 0.17 |
| Fallen leaves | 1.86 | 30.5 | 2.0 | 7.1 | 31.9 | 4.7 | 2.6 | 0.05 | 0.02 | --- | 0.46 | 0.19 |
| Total | 22.74 | 197.7 | 30.5 | 183.5 | 102.4 | 28.4 | 19.3 | 0.20 | 0.08 | --- | 1.09 | 0.66 |

Kg/ha

in a yield of 45 t/ha in the sixth crop.  Thus, to maintain
soil fertility and high yields of continuously grown cassava,
it is important to apply enough K to prevent soil exhaustion.

Once exhausted the soil may require rather high fertilizer
applications to restore its productivity.  Figure 4 shows the
response to N, P and K in a well-fertilized and in an exhaust-
ed soil.  In the well-fertilized plots yields were very high
and there was no response to N or P and only a minor response
to K.  In the exhausted soils cassava yields were much lower
and there was a significant response to N, P, and especially
to K.  Even application of 100 Kg N, 100 Kg P and 100 Kg K/ha
did not restore cassava yields to those levels obtained without
fertilization in the non-exhausted plots.  On the other hand,
in the long-term fertility trial mentioned above, plots that
were nutritionally exhausted after 5 consecutive cassava crops
with only one initial fertilization, recuperated their produc-
tivity completely with the application of 200 Kg N, 175 Kg P
and 250 Kg K/ha with the sixth crop (Figure 5).  Thus, in soils
that are exhausted due to continuous cropping without adequate
fertilization, their productivity can be restored fairly easi-
ly by heavy application of fertilizers.  However, if productiv-
ity is lost due to erosion, the recuperation of these soils is
more complicated and requires a combination of soil management
practices besides fertilization to restore productivity and pre-
vent further erosion.


Nutrient Absorption and Distribution

By periodic sampling and analysis of cassava plants it is
possible to determine the accumulation and distribution of dry
matter (DM) and nutrients during the growth cycle.  Thus,
Nijholt in 1935 determined how dry matter and nutrients are
partitioned during a 14-month growth cycle.  Figure 6 shows
that DM accumulation was slow during the first 2 months, then
increased, and remained fairly constant during the entire growth
cycle, decreasing only after 12 months.  Roots became the domi-
nant sink after the third month.  At harvest about two thirds
of total DM produced had accumulated in the roots while the rest
was mainly present in the stem, with very little in leaves.
Dry matter in leaves increases rapidly in the first 3-4 months,
after which it remains constant or decreases as new leaf forma-
tion is offset by simultaneous leaf fall.  Figure 6 shows that
N accumulates mainly in leaves during the first half of the
growth cycle, but due to leaf fall, much of this N returns to
the soil, or accumulates in stems and roots in the latter part
of the cycle.  Phosphorus and K is absorbed by the plant at a
nearly constant rate throughout the growth cycle, accumulating
mainly in the swollen roots, with a much smaller proportion in
the tops, returning to the soil in fallen leaves.  Calcium and

magnesium accumulate mainly in the stem; Ca also accumulates in older leaves which later fall off, returning as much as 35% of total absorbed Ca to the soil during the growth cycle.

Figure 7 shows the total absorption of major and secundary elements during a 12 month growth cycle of both fertilized and unfertilized cassava in Carimagua in the eastern plains of Colombia. Due to lack of rainfall from the second to the fifth month absorption of all nutrients slowed down in that period but increased again with the onset of rains in the sixth month. Unfertilized plants accumulated nutrients at a much lower rate throughout the growth cycle and essentially stopped accumulating after the ninth months, while fertilized plants absorbed nutrients throughout the entire cycle.

Nutrient Concentration Within the Plant

The concentration of nutrients within the plant change continuously during the growth cycle and varies between the different plant tissues, and with the age of that tissue. Figure 8 shows how the concentrations of major and secundary elements in various tissues changed with time in one experiment in Quilichao. In general, N, P, K concentrations were high in the first three months, then decreased and stabilized around the fourth month. On the other hand, Ca and S concentrations in upper leaves tended to increase with time, while Mg levels remained rather constant. However, this pattern can change markedly under different climatic conditiors. Thus, Figure 9 shows the change in concentration during the growth cycle in Carimagua. Due to the severe dry season from December to April, nutrient concentrations decreased during that period and increased again with the onset of rains, stabilizing only after the eighth month.

Table 7 shows the nutrient concentrations of various tissues in different parts of the plant at 3-4 month of age, both for fertilized and unfertilized cassava in Carimagua. At this time of the growth cycle leaves are generally sampled for diagnostic purposes. From Table 7 it is clear that N, P and S concentrations are highest in the leaves, followed by stem and lowest in the petioles. Because nutrient concentrations are quite different in leafblades and the corresponding petioles, it is imperative not to mix those two tissues in the same sample if those samples are analyzed for diagnostic purposes. Potassium concentrations are highest in petioles followed by stems and leafblades, while Ca and Mg concentrations are highest in stems, followed by petioles and leafblades. In general, N, P, K, and S concentrations decrease from the upper to the lower part of the plant; Mg concentrations in leafblades and stem also decrease while those in petioles increase from top to bottom of the plant. Calcium concentrations in leafblades and

258

TABLE 7. NUTRIENT CONCENTRATION IN VARIOUS PLANT PARTS OF FERTILIZED AND UNFERTILIZED CASSAVA MVEN 77, AT 3-4 MONTHS AFTER PLANTING IN CARIMAGUA

| Fertilized | N | P | K | Ca | Mg | S | Fe | Mn | Zn | Cu | B |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | ppm | | |
| **LEAF BLADES** | | | | | | | | | | | |
| upper | 5.19 | .38 | 1.61 | 0.76 | .28 | .30 | 398 | 177 | 47 | 10.6 | 26 |
| middle | 4.00 | .28 | 1.36 | 1.08 | .27 | .26 | 430 | 207 | 63 | 9.6 | 30 |
| lower | 3.55 | .24 | 1.30 | 1.40 | .22 | .23 | 402 | 220 | 77 | 8.5 | 37 |
| fallen | 1.11 | .14 | 0.54 | 1.88 | .23 | .19 | 3333 | 247 | 120 | 8.9 | 38 |
| **PETIOLES** | | | | | | | | | | | |
| upper | 1.49 | .17 | 2.18 | 1.58 | .36 | .10 | 57 | 238 | 33 | 4.9 | 17 |
| middle | 0.84 | .09 | 1.84 | 2.58 | .41 | .07 | 88 | 359 | 49 | 3.0 | 14 |
| lower | 0.78 | .09 | 1.69 | 3.54 | .42 | .07 | 95 | 417 | 70 | 3.2 | 15 |
| fallen | 0.69 | .06 | 0.82 | 3.74 | .20 | .08 | 294 | 471 | 155 | 3.1 | 17 |
| **STEM** | | | | | | | | | | | |
| upper | 2.31 | .23 | 2.09 | 2.09 | .47 | .14 | 94 | 140 | 37 | 9.8 | 14 |
| middle | 1.57 | .21 | 1.26 | 1.30 | .26 | .11 | 110 | 120 | 46 | 10.8 | 12 |
| lower | 1.37 | .28 | 1.14 | 1.31 | .23 | .09 | 210 | 99 | 36 | 10.0 | 10 |
| **ROOTLETS** | 1.71 | .19 | 1.03 | 0.71 | .33 | .20 | 3780 | 368 | 136 | 136 | 10 |
| **THICKENED ROOTS** | 0.88 | .14 | 1.05 | 0.16 | .06 | .05 | 127 | 15 | 15 | 3.9 | 4 |
| **Unfertilized** | | | | | | | | | | | |
| **LEAF BLADES** | | | | | | | | | | | |
| upper | 4.57 | .34 | 1.29 | 0.68 | .25 | .29 | 198 | 128 | 49 | 9.9 | 26 |
| middle | 3.66 | .25 | 1.18 | 1.08 | .27 | .25 | 267 | 185 | 66 | 8.7 | 37 |
| lower | 3.31 | .21 | 1.09 | 1.48 | .25 | .25 | 335 | 191 | 89 | 7.6 | 42 |
| fallen | 2.31 | .13 | 0.50 | 1.69 | .25 | .22 | 4850 | 209 | 121 | 9.4 | 39 |
| **PETIOLES** | | | | | | | | | | | |
| upper | 1.50 | .17 | 1.60 | 1.32 | .37 | .10 | 79 | 172 | 40 | 4.4 | 16 |
| middle | 0.70 | .10 | 1.32 | 2.20 | .43 | .10 | 76 | 304 | 72 | 2.9 | 15 |
| lower | 0.63 | .09 | 1.35 | 2.96 | .45 | .13 | 92 | 361 | 110 | 2.8 | 15 |
| fallen | 0.54 | .05 | 0.54 | 3.52 | .41 | .13 | 271 | 429 | 94 | 2.5 | 18 |
| **STEMS** | | | | | | | | | | | |
| upper | 1.64 | .20 | 1.22 | 1.53 | .32 | .19 | 133 | 115 | 36 | 9.7 | 14 |
| middle | 1.03 | .18 | 0.87 | 1.45 | .30 | .16 | 74 | 103 | 39 | 8.9 | 13 |
| lower | 0.78 | .21 | 0.81 | 1.19 | .32 | .16 | 184 | 95 | 54 | 7.9 | 10 |
| **ROOTLETS** | 1.52 | .19 | 1.02 | 0.77 | .39 | .16 | 5986 | 191 | 165 | 165 | 10 |
| **THICKENED ROOTS** | 0.42 | .10 | 0.71 | 0.13 | .06 | .05 | 127 | 10 | 16 | 3.0 | 4 |

petioles increase markedly from top to bottom and are highest
in the fallen leaves, especially in the petioles.  As mention-
ed above, cassava roots are very high in K, followed by N, and
are relatively low in P, Ca, Mg and S.

Unlike most macro nutrients, the minor elements (except
Cu) tend to have highest concentrations in the bottom part of
the plant and especially in the fallen leafblades and petioles.
Copper concentrations are slightly higher in the upper than low-
er part of the plant and are much higher in stem and leafblades
than petioles.  Iron concentrations are very low in petioles
while Mn concentrations are high compared with those in leaf-
blades.  Thus, each element has a different concentration pro-
file within the plant depending on its mobility and function.

In unfertilized plants, nutrient concentrations tend to
be lower in all tissues, although some tissues are more sensi-
tive to nutrient deficiencies than others.  Upper leafblades
are very sensitive to nutrient fluctuations and thus are consid-
ered the best indicator tissue.  Upper petioles are very sensi-
tive to K and Ca supply, but tend to be more variable than leaf-
blades, and therefore are less suitable as indicator tissue.


## Diagnosis of Nutrient Deficiencies and Toxicities

Before a nutritional problem can be corrected it is essen-
tial to diagnose correctly the nature of the problem, whether
it is a deficiency or toxicity and which element or elements
are involved.  Nutritional problems are generally diagnosed by
visual observation of symptoms, by soil or plant tissue analy-
ses, or by observation of plant response to specific nutrient
applications.

Symptoms of deficiencies or toxicities in cassava have
been described and photographed by Asher *et al* (1980), Howeler
(1981), Lozano *et al* (1981) and an audiovisual unit is avail-
able at CIAT.  These symptoms will be briefly described for
each element below.


## Soil Analyses

Soil analyses have the advantage over tissue analyses that
the diagnosed problem can be corrected before the crop is plant-
ed.  However, soil analyses determines only the "available"
fraction of the nutrient present in the soil and the determina-
tion of this fraction depends on the extractant and methodolo-
gy used in the laboratory.  There is not enough standardization
of methodologies among laboratories and no one method is opti-
mal for all soils.  Thus, in the interpretation of the results

it is important to consider the extractant and methodology used in the laboratory. In any case, the "amount" of available nutrient is only on index figure, which has to be correlated with plant response, but should never be interpreted as equivalent of so many kilos of available nutrient per hectare. Soil and tissue analyses results are interpreted by comparing the obtained values with so-called "critical levels" or critical ranges determined for each element for each crop. Critical levels of deficiency are often defined as the concentration of a particular nutrient in the soil or plant tissue below which its application has a significant effect in increasing yield, and above which no response to its application is expected. The critical level is often taken as the level that corresponds with 90 or 95% of the maximum yield as calculated from the curve that relates yield with nutrient content. Thus, in Figure 10 relative yields of cassava were plotted against the available P content and the exchangeable K content of the soil, both extracted with Bray II solution.

From these curves critical levels of 4 ppm P and 0.17 me K/100 gm dry soil were calculated. Thus, P and K applications to cassava are only recommended if the Bray II - P and K contents are below 4 ppm and 0.17 me/100 gm, respectively. Similarly, relating the average relative yields, of 42 cassava varieties with soil pH, percent Al saturation and exchangeable Ca content, critical levels of pH 4.65, 80% Al saturation and 0.25 me Ca/100 gm were calculated from a lime trial in Carimagua (Figure 11). However, in the Quilichao soil with 80% Al and 0.70 me Ca/100 gm, cassava yields (average of 30 varieties) were only depressed to 90% of relative yield at a pH of 4.0. Thus, the critical level for soil pH is often dependent on other soil characteristics such as Al-saturation and Ca and Mg contents in acid soils or on salinity and Na saturation in alkaline soils. Table 8 indicates critical levels of soil parameters for cassava as reported in the literature. These are not absolute values, because they vary somewhat with varieties, climate and other soil characteristics, but they are a useful guide for interpreting soil analyses data.

Tissue Analyses

When analyzing plant tissue the total concentration of nutrient in that tissue is determined. This is essentially independent of methodology, and plant tissue analyses therefore vary little among laboratories. Also, tissue analyses determine the amounts of each nutrient the plant has actually absorbed and is thus a good indicator of the plant's nutritional status and the soil's nutrient supplying power. However, plant tissue analyses often diagnose a nutritional problem too late to correct the problem in the present crop; they only may prevent the same problem in the next crop. As mentioned above,

261

TABLE 8.  CRITICAL LEVELS OF SOIL PARAMETERS FOR CASSAVA

| Parameter | Critical level | Method of analysis* | References |
|---|---|---|---|
| pH | 4.6 - 7.8 | 1:1 soil-water ratio | CIAT (1977-1979) |
| Al (me/100 gm) | 2.5 | 1 $\underline{N}$ KCl | Howeler (1978) |
| Al-sat (%) | 80 | Al/(Al + Ca + Mg + K) | CIAT (1979) |
| P (ppm) | 7 | Bray I | Howeler (1978) |
| | 8 | Bray I | Kang *et al* (1980) |
| | 6 | Bray II | CIAT (1985a) |
| | 8 | Bray II | Sithibusaya (1978) |
| | 10 | Bray II | Howeler (1978) |
| | 8 | Olsen-EDTA | Howeler (1978) |
| | 9 | North Carolina | Howeler (1978) |
| K (me/100 gm) | 0.09 - 0.15 | $NH_4$ - acetate | Obigbesan (1977) |
| | 0.10 | $NH_4$ - acetate | Sithibusaya (1978) |
| | 0.17 | Bray II | CIAT (1985a) |
| | 0.15 | North Carolina | Howeler (1978) |
| Ca (me/100 gm) | 0.25 | $NH_4$ - acetate | CIAT (1979) |
| Conductivity (mmhos/cm) | 0.5 - 0.7 | Saturation extract | CIAT (1977) |
| Na-sat. (%) | 2.5 | $NH_4$ - acetate | CIAT (1977) |
| Zn (ppm) | 1.0 | North Carolina | Howeler (1978) |
| Mn (ppm) | 5-9 | North Carolina | Howeler (1978) |
| $SO_4$-S (ppm) | 8 | --- | Ngongi *et al* (1977) |

\*     Bray I       = 0.025 $\underline{N}$ HCl + 0.03 $\underline{N}$ $NH_4F$

       Bray II      = 0.1 $\underline{N}$ HCl + 0.03 $\underline{N}$ $NH_4F$

       Olsen-EDTA   = 0.5 $\underline{N}$ $NaHCO_3$ + 0.01 $\underline{M}$ Na-EDTA

       North Carolina = 0.05 $\underline{N}$ HCl + 0.025 $\underline{N}$ $H_2SO_4$

       $NH_4$ - acetate   = 1 $\underline{N}$ $NH_4$ - acetate at pH 7

nutrient concentrations vary considerably among different tis-
sues and parts of the plant and change during the growth cycle.
For that reason, only a specific indicator tissue should be
sampled at a certain time during the growth cycle.   Only when
sampling procedures are standardized is it possible to compare
analyses results with published data and interpret these results
in any meaningfull fashion.   Howeler (1983) reported recommend-
ed sampling procedures and critical levels for a number of tro-
pical crops.   In case of cassava, it is recommended to sample
only the youngest fully-expanded leafblades of 3-4 month old
plants.   If at that time plant growth is limited due to drought
or low temperatures, sampling should be delayed until 1-2 months
after new vigorous growth has resumed.   Table 9 shows the nutri-
ent content of YFEL-blades corresponding to deficient, low, suf-
ficient, high or excessive levels.   In general, fertilization
is recommended if the nutrient content is below the sufficiency
range.   Critical levels of nutrient deficiencies, as reported
in the literature (Howeler, 1981) generally fall somewhere
within the sufficiency range.   Figure 12 shows the determina-
tion of the critical Mg level in YFEL-blades of 3-month old
plants.   These levels have been determined for all major and
secundary elements in field trials and for most minor elements
in nutrient solution trials.   Again, these values are a useful
guide for interpreting tissue analyses results, but may vary
somewhat for different varieties, climatic conditions and soils.

In order to supply the plants with the nutrients required
for optimal production it is important to know the plant s nu-
trient requirements, diagnose correctly any deficiency or toxi-
city and use adequate measures to correct these problems.   The
following section describes these points for each element sepa-
rately.

Nitrogen Deficiency

Nitrogen is a basic component of protein, chlorophyl, enzy-
mes, hormones and vitamins.   It is also a constituent of the
cyanogenic glycosides linamarin and lotaustralin, which produ-
ce hydrocyanic acid   (HCN) when cells are damaged.   HCN is the
bitter, highly toxic component of cassava leaves, stems and
roots, which must be eliminated before consumption by drying
or cooking the roots.   Nitrogen deficiency is most common in
very sandy or low organic matter (D.M.) soils, or in acid soils
in which toxic levels of Al and/or Mn reduce the rate of decom-
position of organic matter.

Cassava plants suffering N-deficiency may not show any vi-
sible deficiency symptoms but are shorter and grow less vigor-
ous than normal.   In some varieties and under severe N- defi-
ciency leaves are slightly lighter green in color, the chloro-
sis being rather uniform throughout the plant.   In nutrient so-

263

TABLE 9.   NUTRIENT CONCENTRATION IN YOUNGEST FULLY-EXPANDED LEAF BLADES OF 3-4 MONTHS
OLD CASSAVA, CORRESPONDING TO VARIOUS NUTRIENT STATUS OF THE PLANT (HOWELER,
1983).

| Element | Nutrient status | | | | |
|---------|-----------|-----------|------------|-----------|--------|
|         | Deficient | Low       | Sufficient | High      | Toxic  |
| N (%)   | < 4.7     | 4.7 - 5.1 | 5.1 - 5.8  | > 5.8     | -      |
| P (%)   | < 0.30    | 0.30 - 0.36 | 0.36 - 0.50 | > 0.50  | -      |
| K (%)   | < 1.0     | 1.0 - 1.3 | 1.3 - 2.0  | > 2.0     | -      |
| Ca (%)  | < 0.65    | 0.65 - 0.75 | 0.75 - 0.85 | > 0.85  | -      |
| Mg (%)  | < 0.27    | 0.27 - 0.29 | 0.29 - 0.31 | > 0.31  | -      |
| S (%)   | < 0.24    | 0.24 - 0.26 | 0.26 - 0.30 | > 0.30  | -      |
| B (ppm) | < 20      | 20 - 30   | 30 - 60    | 60 - 100  | > 100  |
| Cu (ppm)| < 5       | 5 - 6     | 6 - 10     | 10 - 15   | > 15   |
| Fe (ppm)| <100      | 100 - 120 | 120 - 140  | 140 - 200 | > 200  |
| Mn (ppm)| < 45      | 45 - 50   | 50 - 120   | 120 - 250 | > 250  |
| Zn (ppm)| < 25      | 25 - 30   | 30 - 60    | 60 - 120  | > 120  |

Deficient  =          80% maximum yield
Low        =  80 -  90% maximum yield
Sufficient =  90 - 100% maximum yield
High       = 100 -  90% maximum yield
Toxic      =          90% maximum yield

lution trials, Forno (1977) observed only slight N-deficiency symptoms in cassava, while sorghum, maize and cotton showed severe symptoms. However, plant growth was severely reduced. This corresponds with observations at CIAT (Lozano *et al*, 1981) in which N-deficiency in cassava resulted mainly in reduced growth rather than deficiency symptoms.

Some of the most dramatic responses to N have been obtained on the sandy soils of Jaguaruna in the state of Santa Catarina in southern Brazil. Figure 13 shows a nearly linear response of two varieties up to levels of 150 Kg N/ha. In this location yields increased from 10 to 35 t/ha by N application in a soil with 89% sand and 0.7% O.M. (Moraes *et al*, 1981). For both varieties highest yields were obtained with a fractioned application with 1/3 applied at 30, 60 and 90 days. Similar results were obtained in Carimagua where cassava responded to the application of 100 Kg N/ha, with highest yields obtained with a fractioned application of 1/3 at 30, 120 and 150 days. However, the yield differences due to time of application were not statistically significant (Figure 14).

In Kerala state of southern India cassava responds principally to the application of N, 100 Kg/ha being the recommended dosis, half applied at planting and half at 2 months (Mandal *et al*, 1971). Similarly, in Thailand, where cassava is generally grown on moderately acid and low O.M. soils the crop responds mainly to application of 50-100 Kg N/ha (Sittibusaya *et al*, 1974).

Many investigators (Vijayan and Aiyer, 1969; Acosta and Perez, 1954; Obigbesan and Fayemi, 1976; Fox *et al*, 1975) found that cassava responded negatively to high levels of applied N. This stimulates top growth excessively resulting in a reduction in root production. Krochmal and Samuels (1970) reported a root yield reduction of 41% and top growth increase of 11% due to high N applications. Also, high levels of N application stimulate production of N-containing compounds such as protein and HCN, but may result in a decrease in starch content.

High levels of N applications may be necessary for cassava forage production since the cutting of tops removes large amounts of N. Figure 15 shows the response to N, P and K application in Carimagua, both in terms of total forage and protein production as well as root yields. There was a highly significant response to application of all three elements up to the highest level of 200 Kg/ha. Application of 200 Kg N/ha increased total forage production from 3.3 to 6.3 t/ha and protein yield from 0.7 to 1.4 t/ha. The latter corresponds to an N-extraction of 224 Kg/ha in the tops. The periodic cutting of tops affected cassava root yields and the response to fertilizers. Without N application forage harvesting reduced root yield about 50%, while with 200 Kg N/ha applied root yields decreased from

265

25 to 16 t/ha, corresponding to a 35% yield reduction (Figure 15B). Application of the highest fertilizer level of 200 Kg /ha of N, P and K resulted in highest forage production of over 8 t/ha (2 t/ha of protein) while still producing 20 t/ha of fresh roots.


## Phosphorus Deficiency

Phosphorus is a basic component of nucleoproteins, nucleic acids and phospholipids as well as all enzymes that play a role in energy transfer. Phosphorus is an important element for the process of phosphorilization, photosynthesis, respiration, and the synthesis of carbohydrates, proteins and fats. Through these processes an adequate P supply is essential for the synthesis of starch and thus for normal root production. Malavolta *et al* (1952) reported a reduction from 32 to 25% of starch in cassava roots when P was not supplied in a nutrient solution experiment, while Muthuswamy (1974) reported no effect of P on the HCN content of roots.

Roots contain relatively small amounts of P, and P extraction from the soil in the root harvest is therefore much lower than that of N or K. However, in Latin America, where the majority of the cassava growing areas are characterized by extremely P-deficient soils, this element most limits cassava yields.

P-deficient plants seldom show clear deficiency symptoms; instead, they are shorter and less vigorous, have thinner stems, an smaller and narrower leaves than normal plants. Root yields can be seriously depressed by P-deficiency. Only in case of extreme deficiency plants have a few dark yellow or orange lower leaves, which later become necrotic and fall off. In the absence of clear deficiency symptoms P deficiency is generally diagnosed from a knowledge about the soil, or from soil or plant tissue analyses. When the soil contains less than 4-5 ppm Bray II-extractable P or YFEL-blades have less than 0.4 ppm P at 3-4 months of age of the plant, it is very likely that the plant will respond to P applications.

It has been clearly shown (Yost and Fox, 1979; van der Zaag *et al*, 1979; Howeler *et al*, 1982) that cassava is extremely dependent on an effective mycorrhizal association for absorption of P from the soil. In soils with a low or ineffective native mycorrhizal population cassava growth and production can be greatly increased by soil inoculation with a highly effective strain of mycorrhiza (see following chapter). In the presence of an effective mycorrhizal population cassava is extremely tolerant of low levels of available P. While corn, and soybean have a critical soil-P level of 14-15 ppm, cassava requires only 8 ppm of Bray-I extractable P (Kang, 1980). Table 10 shows that in nutrient solutions in the absence of a mycorrhizal

TABLE 10. EXTERNAL P REQUIREMENT OF VARIOUS CROPS IN TERMS OF "AVAILABLE" SOIL P CONCENTRATION IN SOIL OR NUTRIENT SOLUTION (Data in ppm)

| Crop | Soil-extract | Soil solution | Nutrient solution |
|------|--------------|---------------|-------------------|
| Cassava | $8\frac{1}{2}$[1] (Bray I) <br> $6$[2] (Bray II) | 0.01 - 0.04[1,3] | 0.9 - 2.4[4,5,6] <br> 0.03[5] |
| Maize | 14[1] (Bray I) | 0.06[7] | |
| Beans | 18[8] (North Carolina) <br> 10-15[10] (Bray II) | 0.06[9] | 0.03[6] |
| Cowpea | | 0.016 - 0.1[11] | 0.03[6] |
| Soybean | 15[1] (Bray I) | 0.018 - 0.2[11] | 0.02[5] |
| Rice | | 0.03 - 0.12[12] | |
| Sorghum | | 0.05[7] | |
| Sweet potato | | 0.10[3,7] | |
| Irish potato | | 0.20[3,7] | |
| Chinese cabbage | | 0.20[7] | |
| Lettuce | | 0.40[7] | |
| Cotton | | | 0.02[5] |

References:

| | | | |
|---|---|---|---|
| 1/ | Kang *et al* (1980) | 7/ | Fox *et al* (1974) |
| 2/ | CIAT (1985a) | 8/ | Goepfert (1972) |
| 3/ | van der Zaag *et al* (1979) | 9/ | CIAT (1978) |
| 4/ | Asher and Edwards (1978) | 10/ | Howeler and Medina (1978) |
| 5/ | Jintakanon *et al* (1982) | 11/ | IITA (1981) |
| 6/ | Howeler *et al* (1982a) | 12/ | IITA (1982) |

association cassava has a very high P-requirement due to a coarse and inefficient root system. However, in natural soils in the presence of an effective mycorrhizal population cassava is extremely efficient in P uptake and has a low external P requirement.

P-deficiency is found principally in Oxisols and Ultisols like the Campo Cerrado and Amazone basin in Brazil, the Llanos Orientales of Colombia, the Llanos of Venezuela and in many parts of humid tropical Africa. In Asia Ultisols are found in Malaysia, parts of southern India and in Indonesia. Many Inceptisols like those of the Andes, parts of the Amazone basin, in Hawaii, Cambodia, India and Indonesia are also characterized by P deficiency and high P fixation.

Phosphorus is generally applied to the soil as highly soluble phosphates such as triple or single superphosphate, mono or diammoniumphosphate or as compound fertilizers. These should be band-applied close to the stake so as to reduce P fixation by the soil as well as weed growth. However, in many acid soils cassava also responds well to rockphosphate applications, especially when partially acidulated or when mixed with elemental S to help dissolve the phosphate. To improve the solubility of rockphosphates or basic slag these sources should be broadcast and incorporated. Because of their lower cost these are attractive sources of P and can be nearly as effective as the soluble sources, especially in very acid soils (Figure 16).

Alternative methods of P application such as foliar applications or stake treatments have been tried in Carimagua and Quilichao. In both locations these methods were found to be ineffective and yields increased only significantly when P-sources were applied to the soil (Table 11). Fractionation of P had no beneficial effect and it is recommended to apply all P at time of planting.

While P is the main limiting element for cassava in many virgin soils, the application of P has a long residual effect. Thus continuous P application builds up the available P content of the soil, improving its productivity. Once the available P level has increased above the critical level further P applications can be greatly reduced or entirely eliminated.


Potassium Deficiency

Potassium is not a basic component of protein, carbohydrates or fats, but plays an important role in their metabolism; K is also essential for translocation of carbohydrates from the top to the roots (Malavolta, 1954). Blin (1905) and Obigbesan (1973) reported that K increased the starch and decreased the

268

TABLE 11.   ALTERNATIVE METHODS OF P APPLICATION IN CASSAVA GROWN IN CIAT-QUILICHAO AND
            IN CARIMAGUA

| Treatments | Quilichao* | Carimagua** |
|---|---|---|
| Check without P | 26.1 | 5.7 |
| 50 Kg P/ha as TSP $\neq$ at planting | 35.6 | 12.1 |
| 50 Kg P/ha as TSP fractionated at 0,30,60,90,120 days | 36.3 | 9.3 |
| 50 Kg P/ha as basic slag at planting | 38.7 | 13.3 |
| 5 foliar applications with 2% $KH_2PO_4$ | 21.3 | 6.9 |
| 5 foliar applications with 5% $KH_2PO_4$ | 25.7 | 7.9 |
| 5 foliar applications with 2% TSP | 24.1 | 3.9 |
| 5 foliar applications with 5% TSP | 25.3 | 6.1 |
| Stake treatment with 5% $KH_2PO_4$ | 25.0 | 6.0 |
| Stake treatment with 10% $KH_2PO_4$ | 26.0 | 2.4 |
| Stake treatment with 5% TSP | 23.5 | 4.1 |
| Stake treatment with 10% TSP | 26.5 | 6.7 |

\*    Average of MCol 1684 and CMC 40

\*\*   MVen 77

$\neq$    TSP: Triple super phosphate

HCN content of the roots. Similarly, Payne and Webster (1956) found highest HCN contents in roots produced on low-K soils.

Like N and P, deficiency of K results mainly in reduced plant height and vigor. Stem internodes are markedly reduced and the upper stem tends to lignify prematurely and grows in zigzag. In general stems are thick and highly branched, producing a prostrate growth habit. Deficiency symptoms in leaves are not often observed. In pot and nutrient solution experiments K-deficient plants have often small and light green leaves at the top of the plant. In the field K deficient plants are seldom chlorotic, but upper leaves are small and lower leaves may be yellow and necrotic along the borders. Some of this necrosis seems to be due to K-deficiency-induced diseases, mainly anthracnose. During a drought K-deficiency causes curling of leaves.

Potassium deficiency in cassava is generally found in tropical soils with low-activity clay such as Oxisols, Ultisols and Inceptisols. While Ultisols and Inceptisols may have reasonable contents of exchangeable K, they have a low K-supplying power and are easily depleted of K after several consecutive cassava harvests (See Figure 3).

Figure 17 shows the response to K in three soils in Brazil. There was only a significant response to K application in the Irará soil with 0.04 me/100 gm. In the other two locations with exchangeable K levels around the critical level, there was no K response. Figure 18 shows that even in a soil with only 0.09 me K/100 gm in Cruz das Almas, Bahia, Brazil, there was no significant K response in the first year. However, in the second and third consecutive cassava crop there was a marked K response up to 100-130 Kg K/ha. Similar results were obtained in Carimagua in a soil with 0.08 me K/100 gm (Figure 19); in the first crop there was no response, but in subsequent crops the response became ever more marked. In the fourth crop the yield of the K check was only 7.8 t/ha compared with 20 t/ha at the highest application rate of 168 Kg K/ha. Many experiments on time of application of K have given somewhat contradictory results. In general there are no significant differences between a basal application at 0 or 30 days or different split applications. A basal application at 30 days after planting has given highest overall yields (Figure 20).

Among different K sources, KCl is the cheapest and most commonly used source. Ngongi *et al* (1977) showed that KCl and $K_2SO_4$ were equally effective K sources, except in soils with low S contents; in those it is recommended to use $K_2SO_4$ or mix elemental S with KCl to prevent the induction of S deficiency by high applications of chlorides.

Figure 21 shows that application of 100 kg K/ha increased the root starch content from 32 to 35%. Higher applications of K had no more beneficial effect. P-application up to 100 Kg P/ha also increased starch content, while N application had no effect at low levels of application and decreased starch content at rates of 200 Kg N/ha.

Deficiency of Ca and Mg

Calcium plays an important role in the supply and regulation of water in the plant, while Mg is a basic component of chlorophyl and is thus essential for photosynthesis.

Symptoms of calcium deficiency are seldom observed in the field. Plants are only slightly smaller and the fibrous root system is less developed. In nutrient solutions severe Ca-deficiency results in short plants, yellowing of leaf margins of older leaves and curling and puckering of leaftips and margins of young leaves. Since Ca is a phloem immobile element, its deficiency affects principally the growing points of both tops and roots. Thus, Ca-deficiency reduces root growth and results in a coarse and stubby root system. In flowing solution culture cassava was found to be more tolerant of extremely low levels of Ca than were maize, sorghum, sunflower and soybean (Edwards *et al*, 1977). Also in very Ca-deficient soils in Nigeria, Edwards and Kang (1978) did not observe Ca deficiency symptoms in cassava, while maize, soybean and lima beans were severely affected. In a sandy soil in Carimagua with only 0.18 me Ca/ 100 gm there was a significant response to application of 100 Kg Ca/ha as incorporated gypsum (Figure 22). When band applied the gypsum was ineffective. Incorporation of calcitic or dolomitic lime also increased yields but not as dramatically as with gypsum. Due to its low Ca content (8-11%) and high cost, gypsum is an expensive source of Ca compared with lime. However, Figure 22 shows that 100 kg Ca/ha as gypsum was more effective than 400 Kg Ca as calcitic lime, both being equivalent to about one t/ha of product to be applied.

Magnesium deficiency symptom are frequently observed in cassava grown on acid Oxisols, Ultisols and Inceptisols. They are characterized by intervenal chlorosis and a distinct yellowing of leaf margins of lower leaves. Under very severe Mg-deficiency plants are reduced in size and lower leaves may be completely yellow with necrosis along leafborders. Cassava was found to be quite susceptible to Mg-deficiency requiring for maximum growth higher Mg-concentrations in nutrient solution than cowpea or cotton (Whitehead, 1979). Also Mg-deficiency symptoms were easily induced by high concentrations of K in nutrient solution (Spear *et al*, 1978). Mg-deficiency can be corrected by incorporation of magnesium oxide and dolomitic lime, or by band application of magnesium sulphate. In a sandy Oxisol

271

in Carimagua with 0.06 me Mg/100 gm there was a significant response to application of 40 Kg Mg/ha, but there were no significant difference between Mg-sources (Figure 23). The cheapest sources were dolomitic lime and magnesium oxide.

## Aluminium and Manganese Toxicity and Low pH

Large parts of the tropics are improductive because the soils are too acid for most cultivated crops and the lack of adequate roads makes transport of lime prohibitively expensive. In these areas cassava is often the staple food because this crop is highly tolerant of low pH and high levels of Al and Mn.

Symptoms of Al-toxicity in the field are seldom observed, except that plants are small and lack sufficient vigor. Under severe Al-toxicity conditions in nutrient solutions lower leaves may have intervenal chlorosis and necrotic spots. High levels of Al have especially a detrimental effect on root growth, which in turn affects nutrient and water absorption. Plants suffering from Mn-toxicity have droopy yellow bottom leaves with brown or black spots along the veins. These leaves may later fall off leaving the plant without recognizable symptoms. Mn-toxicity occurs only in very acid soils high in Mn and mainly in areas of poor drainage, which enhances the solubility of Mn due to reduction processes. Mn-toxicity not only reduces the vigor of plant tops but also seriously affects the root system. Compared with other crops cassava is relatively tolerant of high levels of Mn. Among 13 plants species studied only three species were more tolerant (Edwards and Asher, unpublished); among cassava cultivars considerable differences in tolerance were also observed. Mn-toxicity in cassava has been reported only in acid Ultisols and Inceptisols in Quilichao, Colombia. Application of lime in acid soils decreases both the concentration of Al and Mn, reducing their toxic effects.

Figure 24 shows that with lime application in Carimagua there was a successive increase in soil pH and decrease in exchangeable Al. Application of 6 t/ha of lime reduced the Al saturation form 85 to 20%. Figure 25 shows that corn, rice, bean and sorghum produced very poorly without lime and required 6 t/ha of lime to reach maximum yields. On the other hand, cowpea and cassava produced still 40% of maximum yield without lime and close to maximum yields with only 2 t lime/ha. Among cassava cultivars there are differences in their tolerance to acid soils and highly tolerant cultivars should be selected for acid-soil regions.

Since cassava is very susceptible to Zn-deficiency application of lime can actually have a detrimental effect by reducing the availability of Zn and other micronutrients. Thus, for maximum beneficial effect liming often has to be accompanied

272

with Zn-application.

## Sulphur Deficiency

Sulphur is a basic component of several amino acids and therefore plays an important role in protein synthesis. When the S-supply is deficient the plant accumulates in its leaves excessive amounts of inorganic N, amino acids and amids, without sufficient protein production (Stewart and Porter, 1969). Sulphur deficiency in cassava is characterized by a uniform yellowing of upper leaves similar to those caused by N deficiency. Usually, the whole plant becomes uniformly chlorotic and leaves remain small. S-deficiency in cassava has been reported in the Llanos Orientales of Colombia in soils with only 4-4.5 ppm $SO_4$-S (Ngongi *et al*, 1977). This deficiency could be induced by high applications of KCl and eliminated by application of $K_2SO_4$ or other sulphate sources as well as by incorporation of elemental S.

## Micro-nutrient Deficiencies

Micro-nutrients are absorbed by the plant in very small quantities but are a basic component of many enzymes and thus play an essential role in most metabolic processes. In cassava there are few reports of micronutrient deficiencies, but they may be more common than is generally recognized. Cassava is especially susceptible to Zn-deficiency and symptoms of severe Zn-deficiency have been observed in acid soils in Colombia, Brazil, Malaysia, Thailand, Nigeria and Mexico as well as in alkaline and/or calcareous soils in Colombia, Cuba and Mexico. Symptoms of Zn deficiency appear as intervenal chlorotic spots or lines on younger leaves. When very severe the whole leave becomes pale green to white, leaflobes become smaller and tend to point outward away from the stem. Oftentimes, lower leaves show necrotic spotting.

On acid soils Zn deficiency can be controlled by incorporation of ZnO or band application of $ZnSO_4.7H_2O$ at the rate of 10-20 Kg Zn/ha. Also effective are foliar applications of 1-2% $ZnSO_4.7H_2O$ or stake treatments in a 2-4% $ZnSO_4.7H_2O$ solution during 15 minutes. In alkaline soils minor element applications to the soil are not very effective and stake treatments or foliar applications are recommended. Table 12 showed that a simple stake treatment with 4% $ZnSO_4.7H_2O$ increased the average · yield of 20 cassava cultivars from 11.5 to 25.0 t/ha. In many plots untreated plants died because of Zn deficiency, while the stake treatment resulted in normal growth.

Copper deficiency results in reduced plant height, chlorosis and curling of upper leaves and necrosis of leaf tips.

273

TABLE 12. ZINC CONTENT OF YOUNGEST FULLY EXPANDED LEAF
(YFEL) BLADES AT 4 1/2 MONTHS AND ROOT YIELD
OF 20 CASSAVA CULTIVARS PLANTED WITH AND
WITHOUT STAKE TREATMENT OF Zn AT CIAT-PALMIRA

| Cultivar | Zn in leaves (ppm) with Zn | Root yield (t/ha) | |
|---|---|---|---|
| | | with Zn | without Zn |
| MPer 176 | 22 | 3.9 | 0 |
| MPer 193 | 19 | 24.9 | 10.7 |
| MPer 196 | 17 | 30.5 | 13.8 |
| MPer 200 | 22 | 35.4 | 15.0 |
| MPer 206 | 20 | 31.1 | 9.0 |
| MPer 211 | 20 | 21.9 | 9.2 |
| MPer 239 | 20 | 25.9 | 13.0 |
| MPer 243 | 24 | 7.6 | 6.5 |
| MPer 244 | 25 | 18.0 | 14.1 |
| MPer 245 | 23 | 1.0 | 0.6 |
| Mper 247 | 22 | 48.7 | 31.3 |
| MPer 252 | 26 | 22.8 | 17.2 |
| MPer 253 | 20 | 44.9 | 10.7 |
| MPer 266 | 20 | 20.4 | 8.1 |
| MCol 22 | 21 | 23.3 | 11.2 |
| MCol 113 | 25 | 35.3 | 9.4 |
| MCol 1438 | 22 | 3.7 | 2.3 |
| MVen 290 | 20 | 8.8 | 3.4 |
| CM 231-188 | 21 | 47.6 | 23.5 |
| CM 498-1 | 18 | 44.8 | 21.2 |
| Mean | | 25.0 | 11.5 |

Lower petioles tend to be long and droopy.

Severe Cu-deficiency has been reported only in peat soils of Malaysia (Chew, 1971); a basal application of 2.5 Kg Cu/ha as $CuSO_4.5H_2O$ increased yield from 4 to 12 t/ha (Chew *et al*, 1978).

Iron deficient plants have smaller but normal-shaped upper leaves that are light-green, yellow or white in color. When severe even the upper petioles are white. Iron deficiency has been observed in calcareous soils of the Yucatan-peninsula of Mexico and in northern-Colombia. A practical solution is probably either a stake treatment with $FeSO_4.7H_2O$ or foliar applications of sulphates or chelates.

Manganese deficiency is characterized by intervenal chlorosis (fish-bone pattern) of middle leaves, similar to Mg-deficiency but generally not present in lower leaves. When severe the whole leaf turns uniformly yellow, very similar to Fe-deficiency or salinity. Manganese deficiency has been observed on alkaline soils in the Cauca Valley of Colombia as well as along the coast in N.E. Brazil. Stake treatments or foliar application with Mn-sulphates or chelates are probably the most practical solutions.

In the field B-deficient cassava plants have chlorotic small spots on middle or lower leaves. However, in nutrient solution B deficient plants have a deformed growing point with very short internodes, and small deformed dark-green leaves. Sometimes the petioles or stem exude a brown gummy substance, which later produce brown lessions. The rootsystem is short and stubby.

Symptoms of B-deficiency have been observed both in the acid soils of Carimagua and Quilichao as well as on alkaline soils at CIAT-Palmira. Applications of 1-2 Kg B/ha, band applied as Borax at time of planting, eliminated these symptoms, increased plant height, increased B levels in the leaves from 3 to 40 ppm, but had no significant effect on yield. Thus, cassava appears quite tolerant of low levels of available B in the soil.

B-toxicity has not been observed under natural conditions, but is easily induced by excessive applications of B to the soil or in stake treatments. Being a phloem immobile element, B toxicity causes necrosis of lower leaves, but the element is not translocated to the growing point; thus plants generally recuperate.

As mentioned above, high levels of lime application may induce minor element deficiencies in acid soils with low minor

element contents. Thus in Carimagua severe symptoms of Zn-deficiency were observed with applications of 2 and 6 t lime/ha resulting in reduced yields. Figure 26 shows that only when lime applications were combined with applications of 10 or 20 Kg Zn/ha did the crop respond positively to high levels of lime. Liming markedly decreased concentrations of Zn and other minor elements in the leaves. Only when Zn was applied did the Zn concentration in the leaves remain above the critical level at high levels of applied lime (Figure 27).

## Soil Salinity, Alkalinity and High pH

While cassava is very tolerant to acid soils, it is quite susceptible to salinity, alkalinity and high pH. Islam (1979) showed that in nutrient solution cassava had optimum growth at pH 5.5 to 7.0 but top growth declined markedly above pH 7.5 - 8.0. The species was among the most tolerant of low pH and most susceptible of high pH (Figure 28). In natural soils high pH is generally associated with high levels of salts (salinity) and Na (alkalinity), poor drainage and minor element deficiencies. The crop usually suffers from a combination of these factors which are difficult to study individually under field conditions. Also, salinity-alkalinity problems occur in spots in the field giving rise to extremely heterogeneous soils and highly variable plant growth. In Figure 29 cassava root yield was related to soil pH, % Na and soil solution conductivity. While there were significant differences among the three cultivars, root yields declined markedly above pH 8.0, above 2.5% Na saturation and 0.5 - 0.7 mmhos/cm of conductivity; yield reductions are probably due to the combined effect of all three factors. In comparison, many other crops tolerate up to 15% Na saturation or 4 mmhos/cm conductivity.

Problems of soil salinity-alkalinity are very costly to resolve. Soil amendments such as gypsum or elemental sulphur are expensive and are only effective when combined with good drainage and adequate, good quality irrigation water. The best solution is to use only irrigation water of low salt content and select crops adapted to high pH and salinity. For cassava the selection of tolerant cultivars is the only practical solution, together with stake or foliar applications of minor elements, especially Zn.

## Response to Organic and Inorganic Fertilization

In many sandy and low-O.M. soils it is often recommended to apply organic manures or incorporate green manures, which both increase the soil's nutrient and waterholding capacity, improve soil structure and supply small amounts of a large number of plant nutrients. Table 13 shows the approximate nu-

276

TABLE 13. NUTRIENT CONTENT (%) OF COMMONLY USED ORGANIC AND INORGANIC MANURES

| Organic manures | N | P | K | Ca | Mg | S |
|---|---|---|---|---|---|---|
| Cow manure (dry) (aprox) | 2.0 | 0.65 | 1.67 | 2.86 | 0.60 | 0.2 |
| Horse manure (dry)(aprox) | 2.0 | 0.65 | 1.25 | 1.07 | 0.60 | 0.2 |
| Chicken manure (dry) (aprox) | 5.0 | 1.31 | 1.25 | 2.86 | 0.60 | 0.8 |
| Wood ash (aprox) | - | 0.87 | 4.20 | 23.20 | 2.11 | 0.4 |
| Compost (dry) (aprox) | 0.5 | 0.06 | 0.08 | 0.32 | 0.10 | - |
| Inorganic manures | | | | | | |
| Urea | 45 | - | - | - | - | - |
| Ammonium sulphate | 21 | - | - | - | - | - |
| Ammonium nitrate | 33 | - | - | - | - | - |
| Mono-ammonium phosphate | 11 | 21 | - | - | - | - |
| Di-ammonium phosphate | 18 | 20 | - | - | - | - |
| Triple superphosphate | - | 20 | - | 14 | - | - |
| Basic slag (aprox) | - | 6 | - | 37 | 1 | - |
| Potassium chloride | - | - | 50 | - | - | - |
| Potassium sulphate | - | - | 42 | - | - | 18 |
| Calcium sulphate (aprox) | - | - | - | 12 | - | 10 |
| Magnesium sulphate | - | - | - | - | 10 | 13 |
| Magnesium oxide | - | - | - | - | 32 | - |
| Calcitic lime (aprox) | - | - | - | 30 | - | - |
| Dolomitic lime (aprox) | - | - | - | 24 | 12 | - |
| Elemental sulphur (aprox) | - | - | - | - | - | 85 |
| 15-15-15 | 15 | 6.5 | 12.5 | - | - | - |
| 10-20-20 | 10 | 8.7 | 16.7 | - | - | - |
| 10-30-10 | 10 | 13.1 | 8.3 | - | - | - |
| 13-26-6 | 13 | 11.3 | 5.0 | - | - | - |

trient content of various organic manures and chemical fertili-
zers.  Organic manures are a good source of nutrients for small
plots and where easily and cheaply available.  However for
larger extentions the amounts required are often not available
or its application becomes impractical.  In that case chemical
fertilizers are equally good sources of nutrients, are cheaper
to transport and apply, but require a more careful monotoring
of the plant's nutrient status to prevent imbalances or defi-
ciencies, especially of micronutrients.  Figure 30 shows the
response of cassava to application of organic manures and che-
mical fertilizers applied at equal levels of P.  While there
was only a minor response to cow manure,  10-30-10 fertilizers
or rock-phosphates, the application of chicken manure increased
yieldsfrom 19 to 31 t/ha.  The total nutrient content of the
chicken manure was considerably higher than that of the chemic-
cal fertilizer, but the greater beneficial effect must be also
due to improved soil structure, presence of essential elements
other than NPK and the stimulation of beneficial soil micro-or-
ganisms such as mycorrhiza.  The highest level of 75 Kg P/ha
corresponded to 575 Kg of 10-30-10 and 4.3 t of dry chicken ma-
nure.  If the manure has to be transported over long distances
or difficult roads the greater amounts of manure required may
be uneconomical compared with chemical fertilizers.

    Incorporation of green manure legumes also improve soil
structure and supply nutrients, either through N-fixation or
by recycling of nutrients that might otherwise have been lost
through leaching.  In Madagascar (Essais de Fumure, 1953; Le
Manioc, 1952)  investigators recommended incorporation of green
manures such as *Mucuna utilis*, *Vigna* or *Crotalaria*, *Crotalaria
juncea*, the most commonly used species, however, is not adapted
to very acid soil (CIAT, 1975).  Figure 31 shows the response
of cassava to incorporation of various green manures in an ex-
hausted soil in Quilichao, either in the presence or absence of
chemical fertilizers.  Chemical fertilizer alone nearly doubled
yields, but incorporation of Kudzu, Zornia or peanuts further
increased yields about 10 t/ha.  Less effective species were
*Centrosema pubescence*, pigeon pea and Indigofera, while velvet
bean and cowpea had a slight negative effect.  Thus, some green
manures can be highly effective in restoring exhausted soils
and improving their productivity.

    Application of chemical fertilizers is generally more prac-
tical and economical when cassava is grown at a somewhat larger
scale.  Table 14 shows the response to NPK application in 24
locations in Colombia, with soils ranging from quite acid to
alkaline and from very infertile to quite fertile.  Of the 24
trials there was a significant N response in only 5 locations,
a P response in 13 locations and a K response in 7 locations.
Thus, of the three major elements N seems to be the least im-
portant, at least in the prevailing cassava soils in Colombia

Similarly in Brazil cassava responded mainly to P with responses to N and K being rare (Gomez and Howeler, 1980).

## Method and Time of Fertilizer Application

The most effective time and method of application has already been discussed for specific elements or fertilizers. In general the rather insoluble fertilizers and soil amendments such as lime, MgO, ZnO, MnO, rockphosphates, basic slag, gypsum and elemental sulphur should be broadcast and incorporated with a disk harrow or rake. Large applications of lime should be divided such that the first half can be plowed in rather deeply and the second half incorporated more shalowly with a disk harrow.

Highly soluble fertilizers can be either broadcast and incorporated, or localized applied in a band or in a hole near the stake. Broadcast applications distribute nutrients more uniformly around the whole rootsystem but the application is therefore also more diluted, certain nutrients (especially P) are more easily fixed, and weed growth is stimulated. Localized application concentrates the nutrients near the cassava plant to enhance its growth rather than those of the weeds. Figure 32 and table 15 show results of trials comparing different methods and times of application in Carimagua. There was a nearly linear response to application of 750 Kg/ha of 10-20-20 and there were no significant differences among broadcast or various forms of localized application. In 1978A and B (Table 15) with the uniform application of 1 t/ha of 10-20-20 there were essentially no significant differences among different times and methods of application.

Localized application reduces weed competition and is most practical in non-mechanized agriculture, while broadcast application may be more convenient in mechanized agriculture. A short band on one side of the stake, made with a pointed hoe and later covered by hoe or foot appears the most practical localized application.

With vertical planting it is convenient to apply fertilizers right after planting and before preemergent herbicide application. With horizontal planting the fertilizer should be band applied under or to the side of the stake and never in direct contact with it. Fertilization can also be delayed until after sprouting and in that case it is applied as a short band near the plant.

TABLE 14. RELATIVE ROOT YIELD RESPONSE OF CASSAVA TO N, P AND K APPLICATIONS IN 24
LOCATIONS IN COLOMBIA WITH HIGHLY VARIABLE SOIL FERTILITY CHARACTERISTICS.

| | | | Soil Analysis | | | | Relative[1] Yield (%) | | |
|------|-----|---------------------------|-----|------|------------|-------------|-----|------|------|
| | | | | % | ppm | me/100 gm | without nutrient |
| | | | pH | O.M. | p[2] | k[2] | N | P | K |
| 1980 | 1. | CIAT Quilichao | 4.3 | 7.1 | 1.8 | .18 | 70* | 41** | 92 |
| | 2. | Mondomito (Cauca) | 4.1 | 5.6 | 1.6 | .14 | 80 | 64** | 70 |
| | 3. | Agua Blanca (Cauca) | 4.4 | 6.1 | 0.8 | .16 | 87 | 57* | 86 |
| | 4. | Caribia (Magdalena) | 6.0 | 1.9 | 83.0 | .12 | 84 | 94 | 99 |
| | 5. | La Idea (Magdalena) | 5.7 | 0.6 | 6.0 | .04 | 72* | 89 | 86 |
| | 6. | La Colorada (Magdalena) | 6.4 | 0.7 | 3.9 | .07 | 79 | 85 | 92 |
| | 7. | Carimagua-Alegría (Meta) | 4.2 | 1.8 | 1.2 | .04 | 63* | 17** | 23** |
| | 8. | Carimagua-Reserva (Meta) | 4.0 | 3.3 | 1.4 | .08 | 81 | 41** | 63* |
| | 9. | Las Leonas (Meta) | 4.1 | 3.7 | 2.0 | .11 | 61* | 36** | 28** |
| | 10. | Puerto Gaitán (Meta) | 4.6 | 0.8 | 2.3 | .05 | 79 | 14** | 43** |
| 1981 | 11. | CIAT-Palmira (Valle) | 6.3 | 4.1 | 16.3 | .58 | 98 | 90 | 89 |
| | 12. | CIAT-Quilichao (Cauca) | 4.3 | 7.0 | 1.8 | .08 | 62* | 39** | 58* |
| | 13. | San Julián (Cauca) | 4.3 | 6.8 | 1.5 | .21 | 100 | 81 | 93 |
| | 14. | Mondomo (Cauca) | 4.2 | 5.6 | 0.5 | .12 | 90 | 60** | 91 |
| | 15. | Tres Quebradas (Cauca) | 4.7 | 8.0 | 0.9 | .13 | 83 | 41** | 76 |
| | 16. | CIAT-Popayán (Cauca) | 5.0 | 28.0 | 0.6 | .27 | 80 | 39** | 74 |
| | 17. | La Idea (Magdalena) | 5.3 | 0.9 | 5.1 | .04 | 84 | 96 | 80 |
| | 18. | La Colorada (Magdalena) | 5.7 | 0.6 | 2.6 | .05 | 100 | 89 | 92 |
| | 19. | Valledupar (Cesar) | 6.5 | 1.5 | 31.3 | .31 | 90 | 95 | 98 |
| | 20. | Carimagua-Alegria (Meta) | 4.2 | 2.0 | 2.8 | .05 | 74 | 6** | 22** |
| 1982 | 21. | San Emigdio (Valle) | 4.8 | 8.2 | 2.1 | .10 | 84 | 100 | 81 |
| | 22. | Pescador (Cauca) | 4.6 | 8.5 | 1.1 | .11 | 60 | 34** | 41* |
| 1983 | 23. | San Martín (Meta) | 4.4 | 4.4 | 4.9 | .21 | 85 | 68 | 73 |
| | 24. | La Libertad (Meta) | 4.4 | 3.3 | 14.5 | .12 | 69 | 88 | 83 |

* and ** = Significant response at 5 and 1%, resp.

1/ Relative yield is yield without N, P, or K as percent of highest yield obtained with the
nutrient added.

2/ Bray II-extractant

280

TABLE 15.    EFFECT OF METHOD OF APPLICATION OF A COMPOUND FERTILIZER (1 t/ha
OF 10-20-20) ON CASSAVA ROOT YIELD DURING TWO PLANTINGS IN CARI-
MAGUA.

| Method of application | 1978A* | 1978 B* |
|---|---|---|
| Broadcast and incorporated without ridges | 15.7 | 20.1 |
| Broadcast and incorporated before ridging | 12.9 | 16.1 |
| Broadcast on ridges, light incorporation | 16.1 | 15.5 |
| Short band near vertically planted stake | 19.0 | 16.7 |
| Short band below horizontally planted stake | 15.5 | 18.3 |
| Two short bands near vertically planted stake | 17.8 | 14.8 |
| Continuous band below horizontally planted stake | 16.3 | 17.0 |
| In circle around vertically planted stake | 17.7 | 16.0 |
| In hole, 5  cm from vertically planted stake | 18.4 | 15.2 |
| In hole directly under vertically planted stake | 18.6 | 18.2 |
| 1/2 broadcast, 1/2 banded at planting | 23.3 | 14.9 |
| 1/2 broadcast at planting, 1/2 broadcast at 60 days | 16.3 | 15.1 |
| 1/2 broadcast at planting, 1/2 banded at 60 days | 15.9 | 15.4 |
| 1/2 banded at planting, 1/2 broadcast at 60 days | 17.8 | 12.9 |
| 1/2 banded at planting, 1/2 banded at 60 days | 18.3 | 17.8 |
| Check without fertilizers | 12.3 | 4.4 |

1978A = Corresponds with beginning of rainy season, 1978B with end of rainy
season.

## SUMMARY AND CONCLUSIONS

Cassava is a plant that grows relatively well on acid and infertile soils where other crops would not produce without lime or fertilizers. However, for high yields the crop requires high levels of fertilization, especially K, which is removed in large quantities with each root harvest. In many acid infertile soils it is recommended to apply a small amount of dolomitic lime (or calcitic lime with MgO) to supply Ca and Mg as nutrients. Initially P is often the most limiting element, but after a few years the level of P application can be reduced while that of K should be increased to prevent soil K exhaustion. Although the plant has large amounts of N in both tops and roots, much of this is returned to the soil in fallen leaves and is recycled. Except in very sandy and low O.M. soils there is a lesser response to application of N than P or K. Of the minor elements Zn is most important. This element can be supplied cheaply as a stake treatment in 2-4% $ZnSO_4.7H_2O$ solution. In general it is recommended to apply rather insoluble fertilizers or soil amendments broadcast and incorporated before planting, while highly soluble sources are best band applied near the stake all at time of planting or fractionated at planting and 2-3 months later in sandy soils.
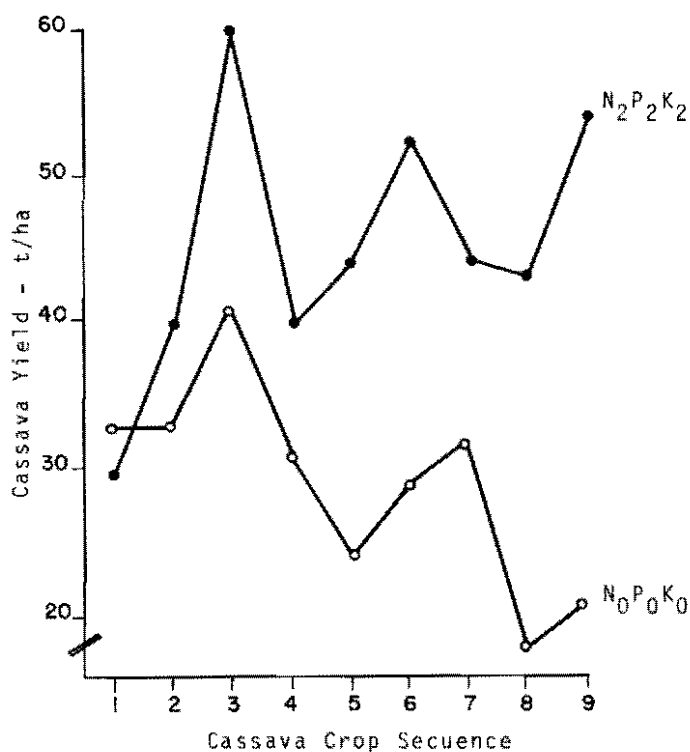
FIGURE 1.  CHANGE IN CASSAVA YIELD DURING NINE SUCCES-
SIVE CASSAVA CROPS WITHOUT APPLIED FERTILI-
ZERS AND WITH THE ANNUAL APPLICATION OF 112
Kg N, 68 Kg P AND 156 Kg K/ha IN MALAYSIA
(Adapted from Chan, 1980).
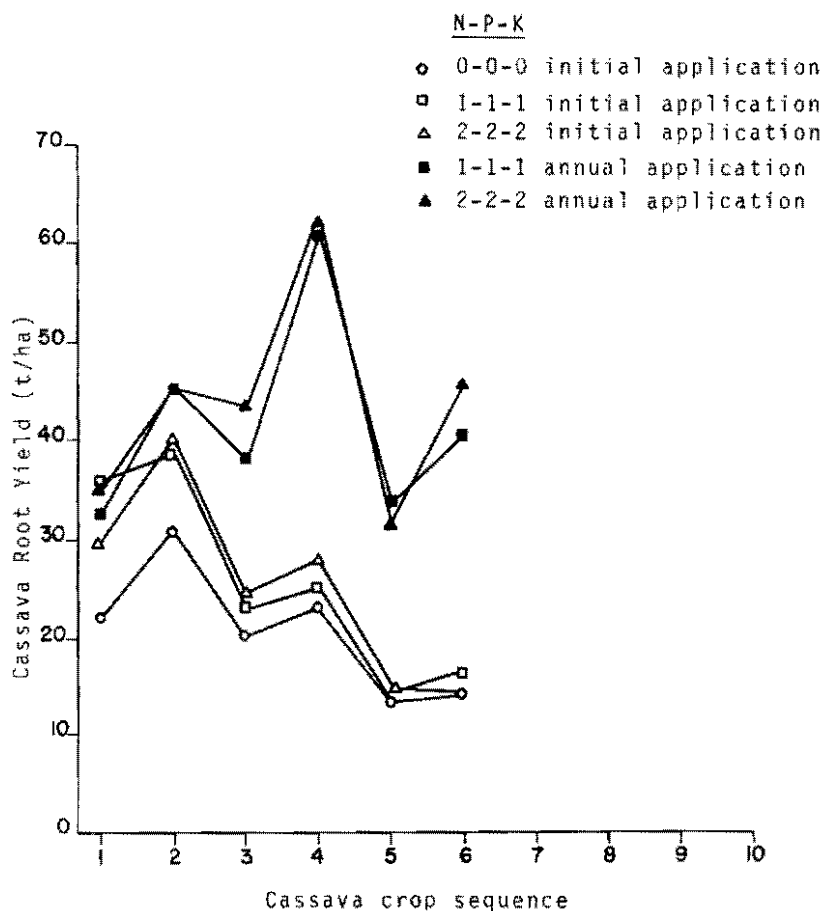
FIGURE 2. CASSAVA ROOT YIELDS DURING SIX CONSECUTIVE CROP-
PING CYCLES WITH EITHER ONE INITIAL OR WITH ANNUAL
APPLICATIONS OF DIFFERENT LEVELS OF NPK FERTILIZERS
IN QUILICHAO. FERTILIZER LEVELS CORRESPOND WITH
0, 100, 200, Kg N; 0, 87, 175 Kg P; and 0, 125 and
250 Kg K/ha
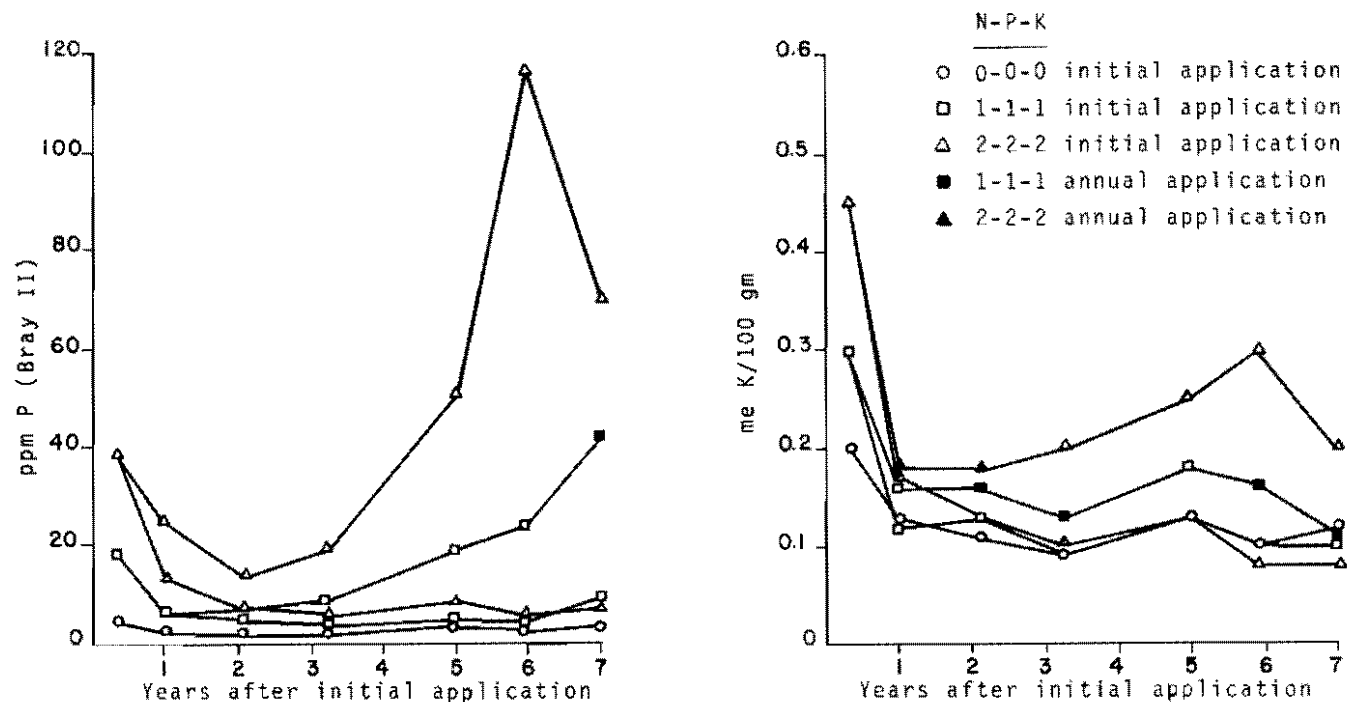
FIGURE 3.   CHANGE IN AVAILABLE SOIL P AND EXCHANGEABLE K CONTENT DURING SIX CONSECUTIVE CROP-
PING CYCLES OF CASSAVA WITH EITHER ONE INITIAL OR WITH ANNUAL APPLICATIONS OF DIF-
FERENT LEVELS OF NPK FERTILIZERS IN QUILICHAO.
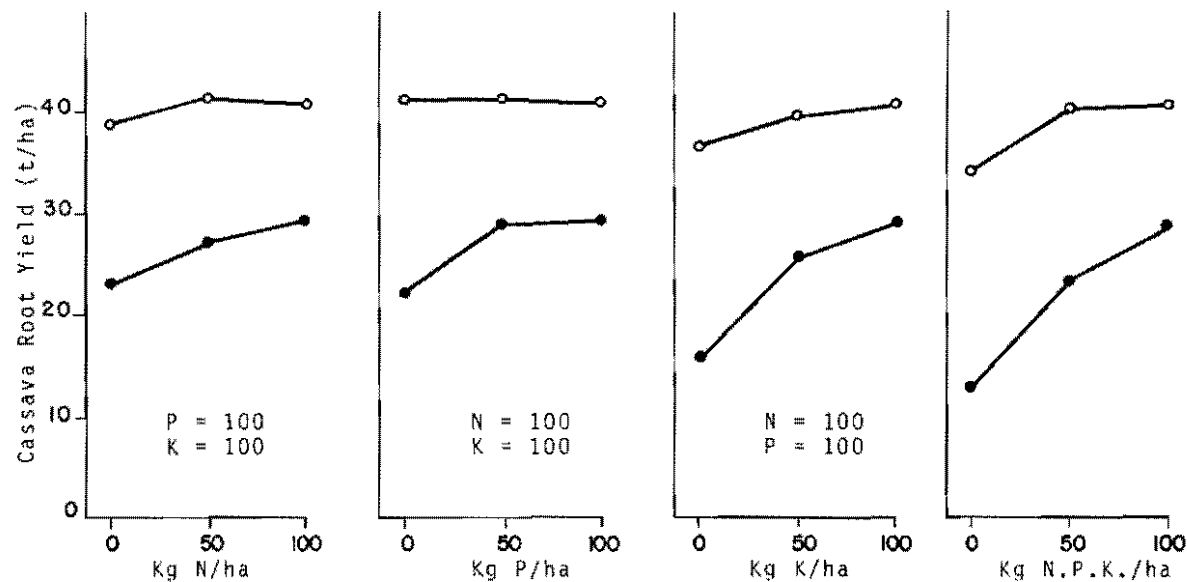
FIGURE 4.  CASSAVA RESPONSES TO APPLICATION  OF N, P AND K BOTH IN A PLOT THAT HAD BEEN WELL FERTILIZED (OPEN SYMBOLS) AND IN A PLOT OF EXHAUSTED SOIL DUE TO CROPPING WITHOUT FERTILIZATION (CLOSED SYMBOLS) IN OUILICHAO.  DATA ARE AVERAGE YIELDS OF MCOL 1684 AND CM 91-3
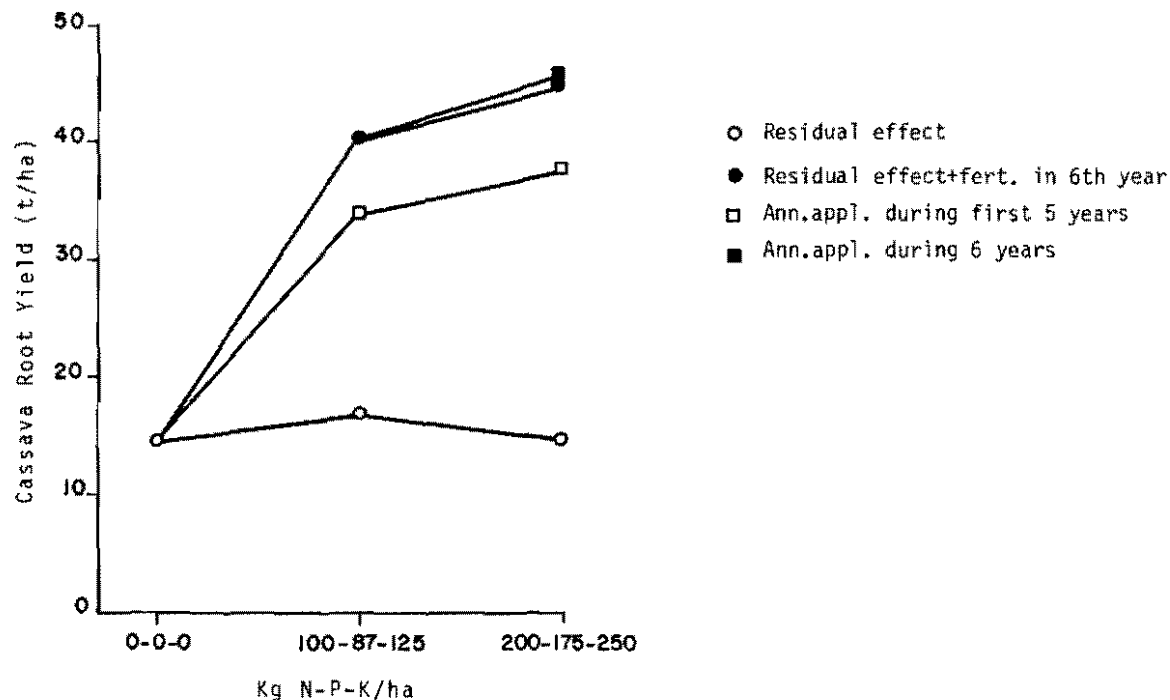
FIGURE 5. RESPONSE OF THE SIXTH CONSECUTIVE
CASSAVA CROP TO THREE LEVELS OF N-P-K,
APPLIED EITHER ONLY WITH THE FIRST CROP,
WITH THE FIRST AND SIXTH CROP, ANNUALLY
WITH THE FIRST FIVE CROPS OR ANNUALLY
WITH ALL SIX CROPS IN QUILICHAO.
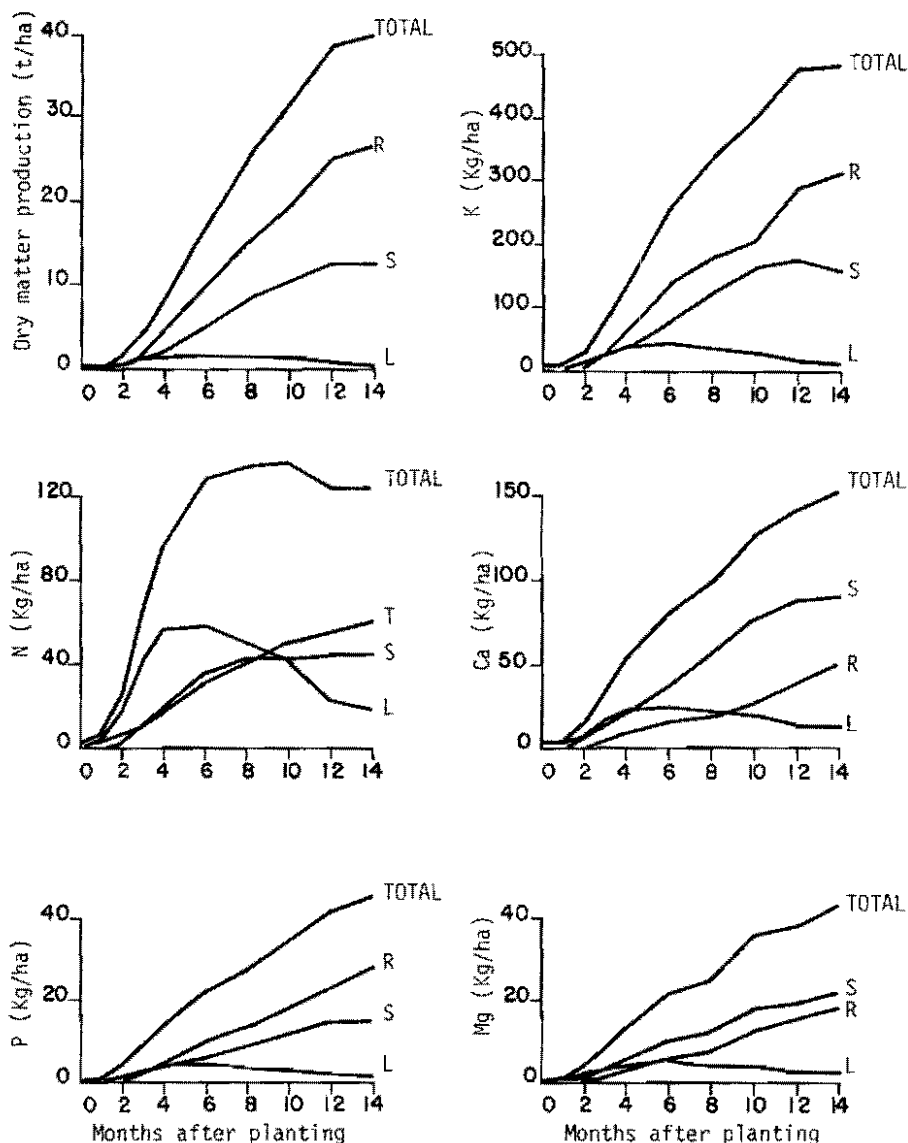
FIGURE 6.  ACCUMULATION OF DRY MATTER, N,P,K, Ca AND Mg IN
LEAVES (L), STEM (S), ROOTS (R) OR IN THE TOTAL
CASSAVA PLANT, cv. SAO PEDRO PRETO DURING A 14
MONTH GROWTH CYCLE IN INDONESIA (Adapted from
Nijolt, 1935)

288
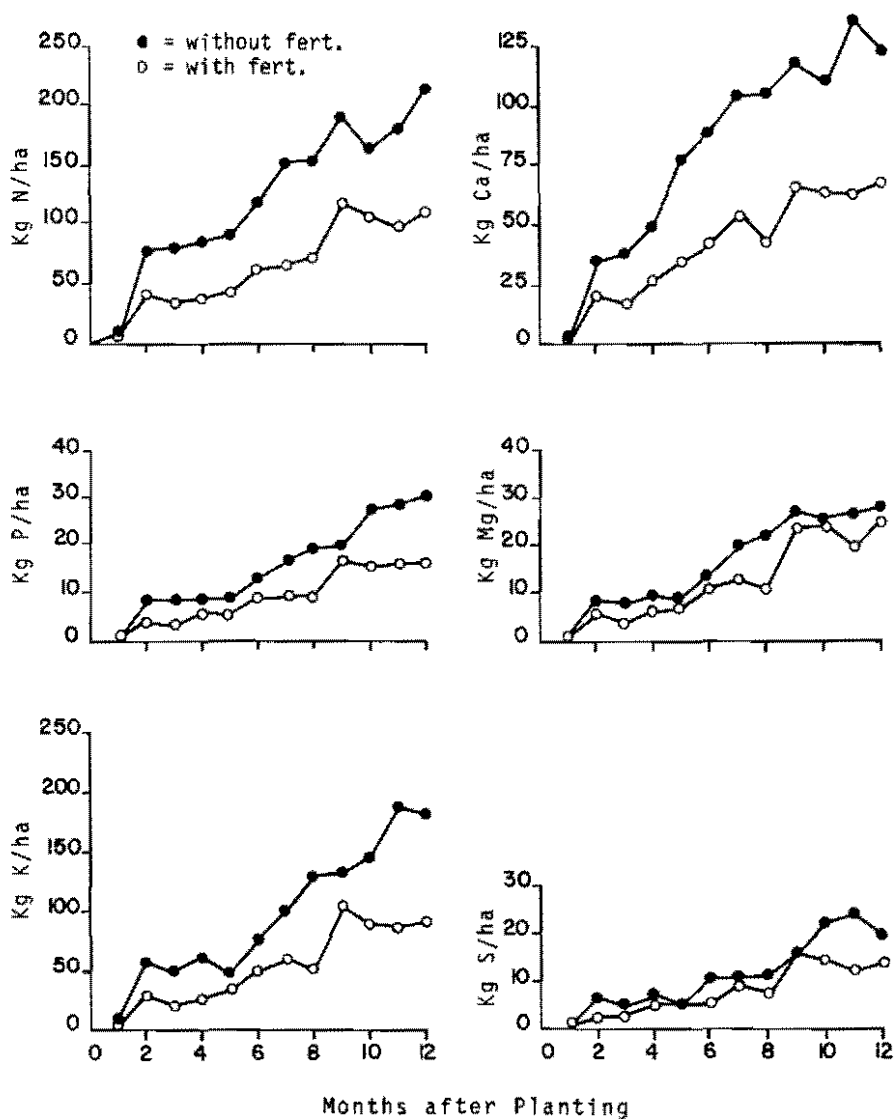
FIGURE 7. ACCUMULATION OF N,P,K,Ca,Mg AND S IN FERTILIZED AND NON-FERTILIZED CASSAVA, cv. MVEN 77, DURING A 12 MONTH GROWTH CYCLE IN CARIMAGUA.
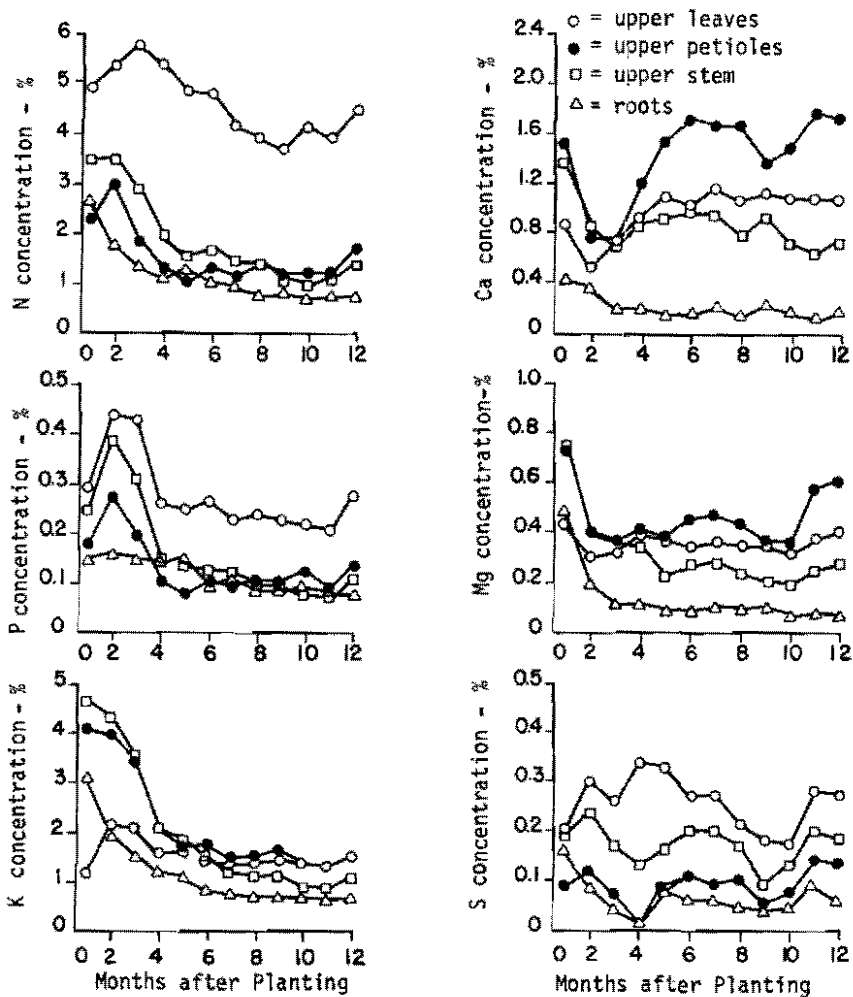
FIGURE 8.   CHANGE IN CONCENTRATION OF N,P,K,Ca,Mg AND S IN
            VARIOUS CASSAVA PLANT TISSUES DURING A 12 MONTH
            GROWTH CYCLE IN QUILICHAO.

290
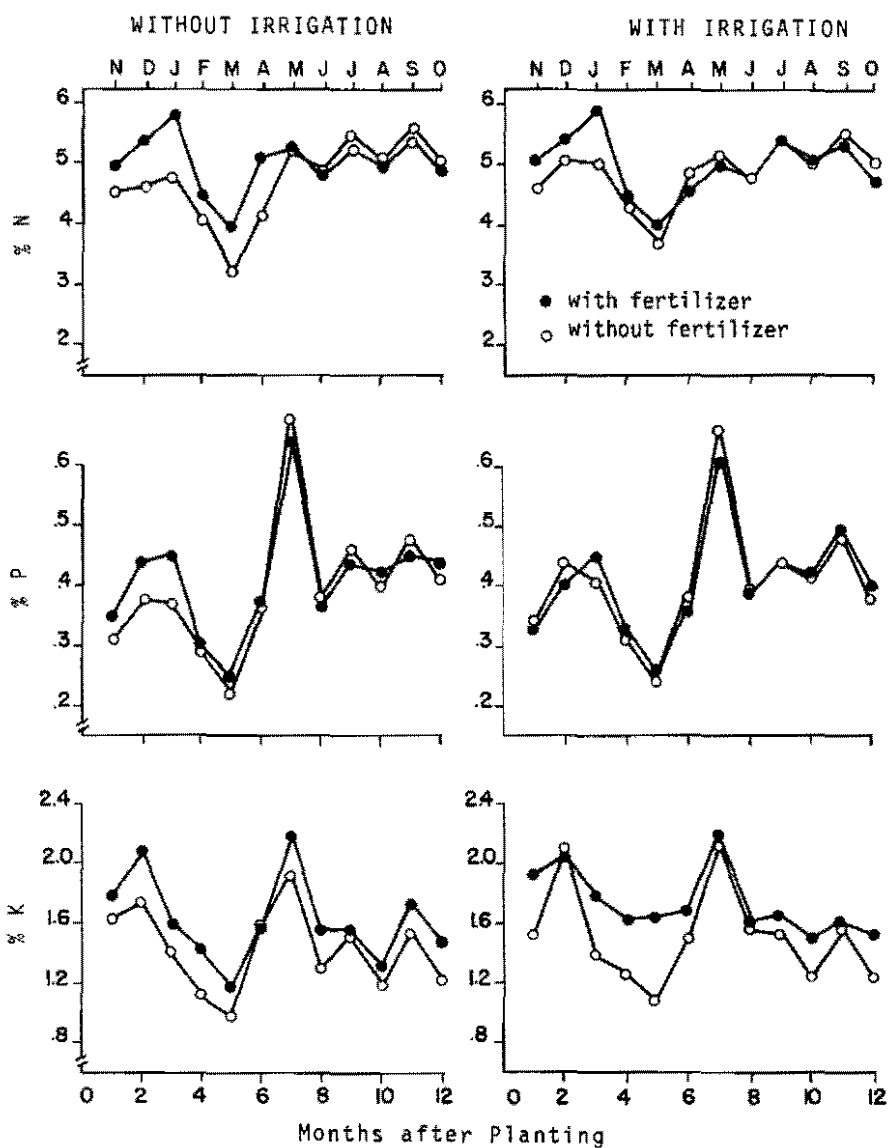
FIGURE 9. CHANGE IN CONCENTRATION OF N,P AND K IN UPPER LEAF-
BLADES DURING A 12 MONTHS GROWTH CYCLE OF FERTILIZED
AND UNFERTILIZED CASSAVA, cv. MVEN 77, GROWN IN CARI-
MAGUA WITH AND WITHOUT IRRIGATION DURING THE DRY SEA-
SON.
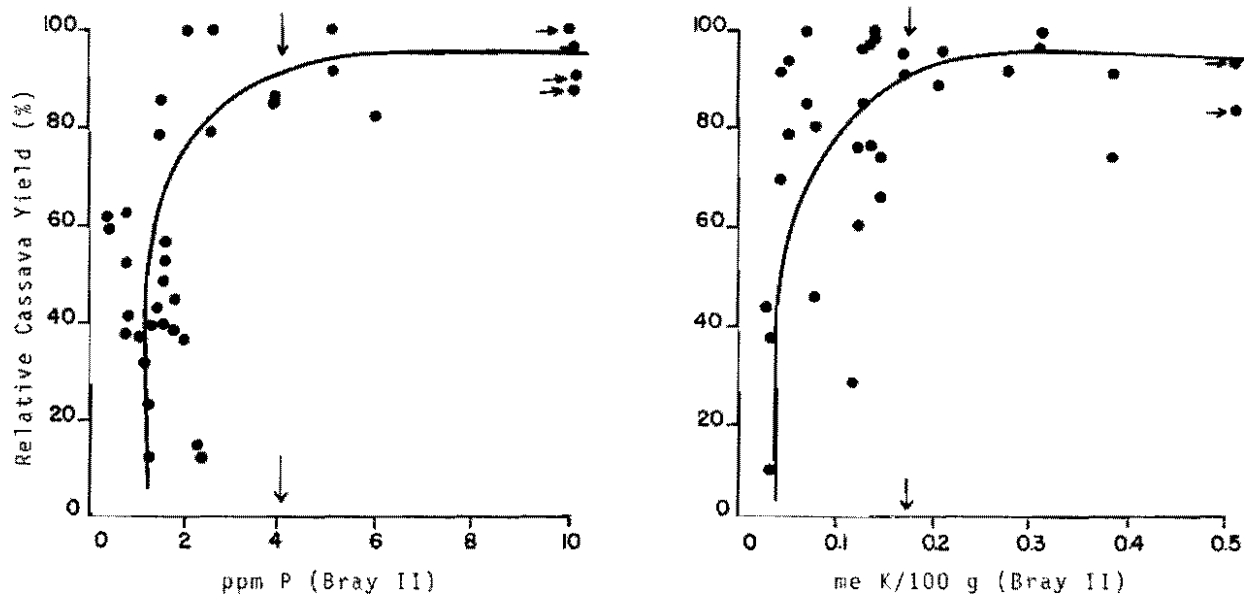
FIGURE 10.  RELATION BETWEEN THE RELATIVE CASSAVA YIELD OF P OR K CHECK PLOTS AND THE
AVAILABLE P (LEFT) OR EXCHANGEABLE K (RIGHT) CONTENT OF SOILS IN 24 NPK
TRIALS IN COLOMBIA.  VERTICAL ARROWS INDICATE THE CRITICAL LEVELS.
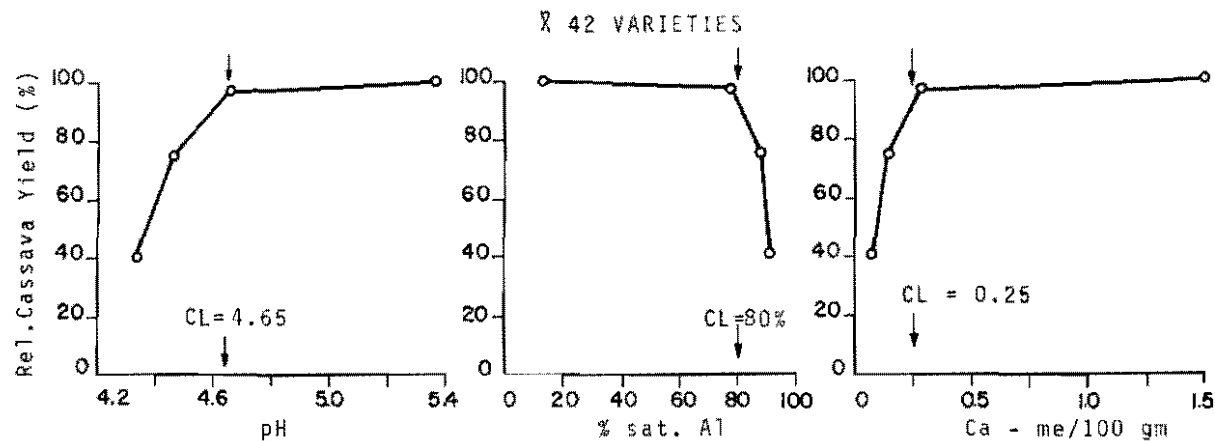
FIGURE 11. RELATION BETWEEN THE AVERAGE YIELD OF 42 CASSAVA VARIETIES AND SOIL pH, % Al SATURATION, AND THE EXCHANGEABLE Ca CONTENT OF THE SOIL IN CARIMAGUA. VERTICAL ARROWS INDICATE THE CRITICAL LEVELS.
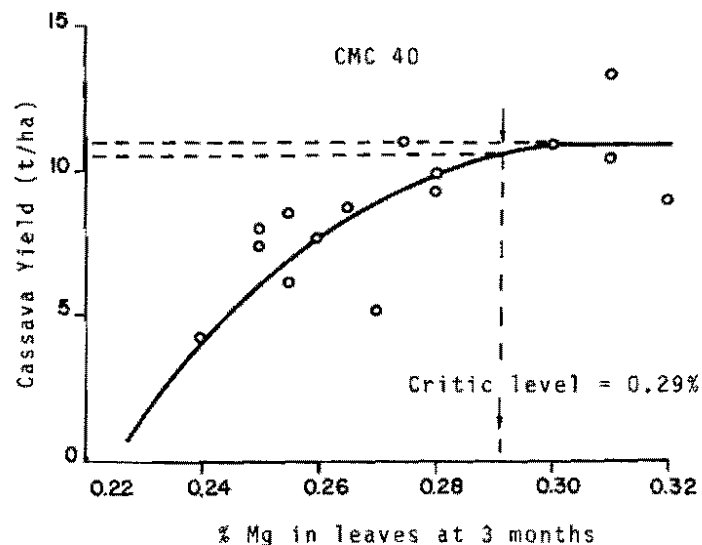
FIGURE 12.  RELATION BETWEEN CASSAVA ROOT YIELD AND THE
Mg CONCENTRATION IN YOUNGEST FULLY EXPANDED
LEAFBLADES OF CMC 40 IN CARIMAGUA.  VERTICAL
ARROW INDICATE THE CRITICAL LEVEL CORRESPOND-
ING WITH 95% OF MAXIMUM YIELD.
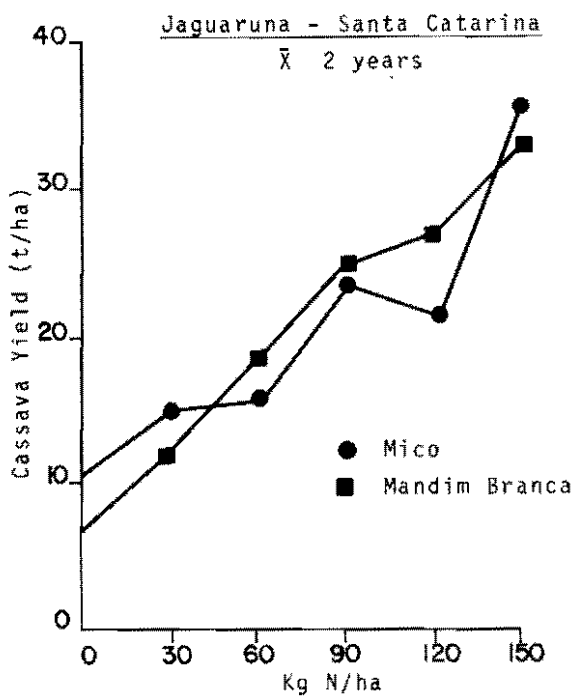
FIGURE 13. RESPONSE OF TWO CASSAVA VARIETIES TO DIFFERENT LEVELS OF APPLICATION OF N IN A SANDY SOIL OF JAGUARUNA, ST. CATARINA, BRAZIL.
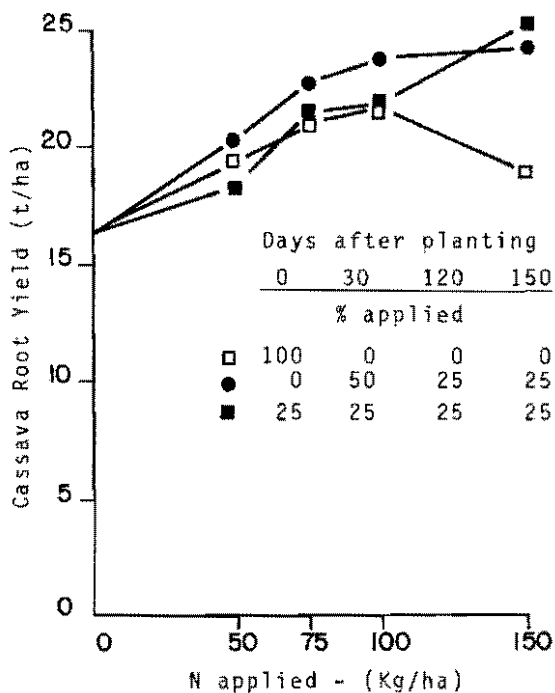
FIGURE 14.  RESPONSE OF CASSAVA, cv. LLANERA TO
DIFFERENT LEVELS AND TIMES OF APPLI-
CATION OF N IN CARIMAGUA.
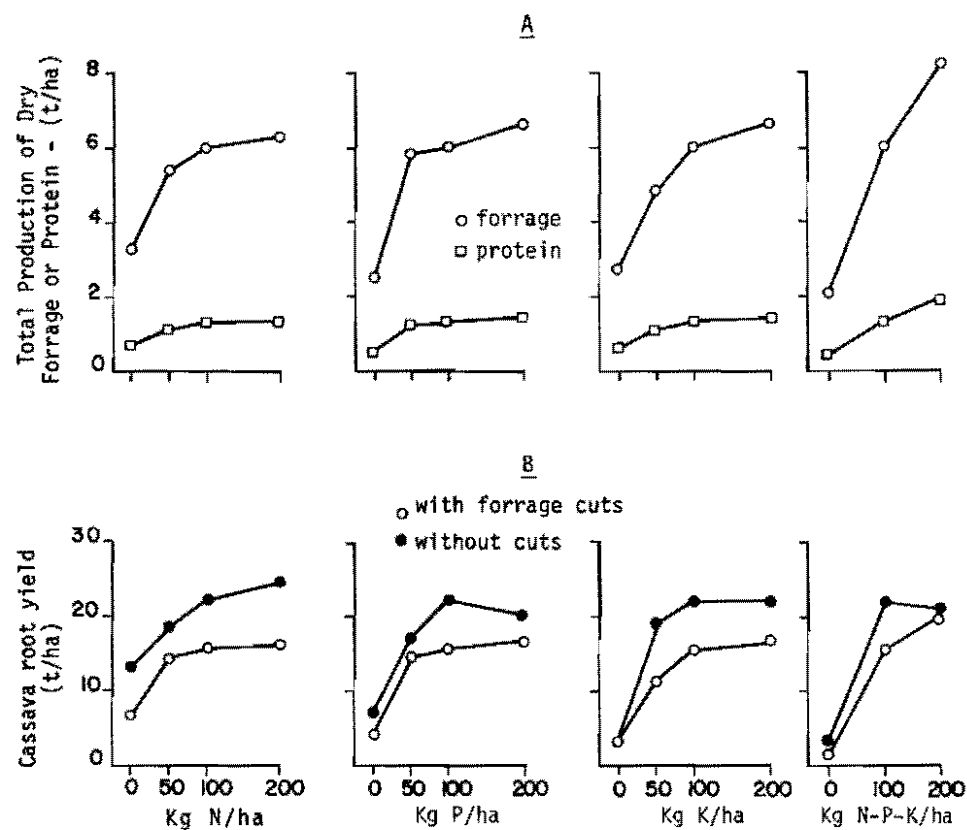
FIGURE 15. EFFECT OF N, P AND K APPLICATION ON TOTAL PRODUCTION OF CASSAVA FORRAGE AND PROTEIN (A), AS WELL AS ITS EFFECT ON ROOT PRODUCTION WITH OR WITHOUT FORRAGE CUTS (B). VARIETY CM 523-7, 14 MONTHS.
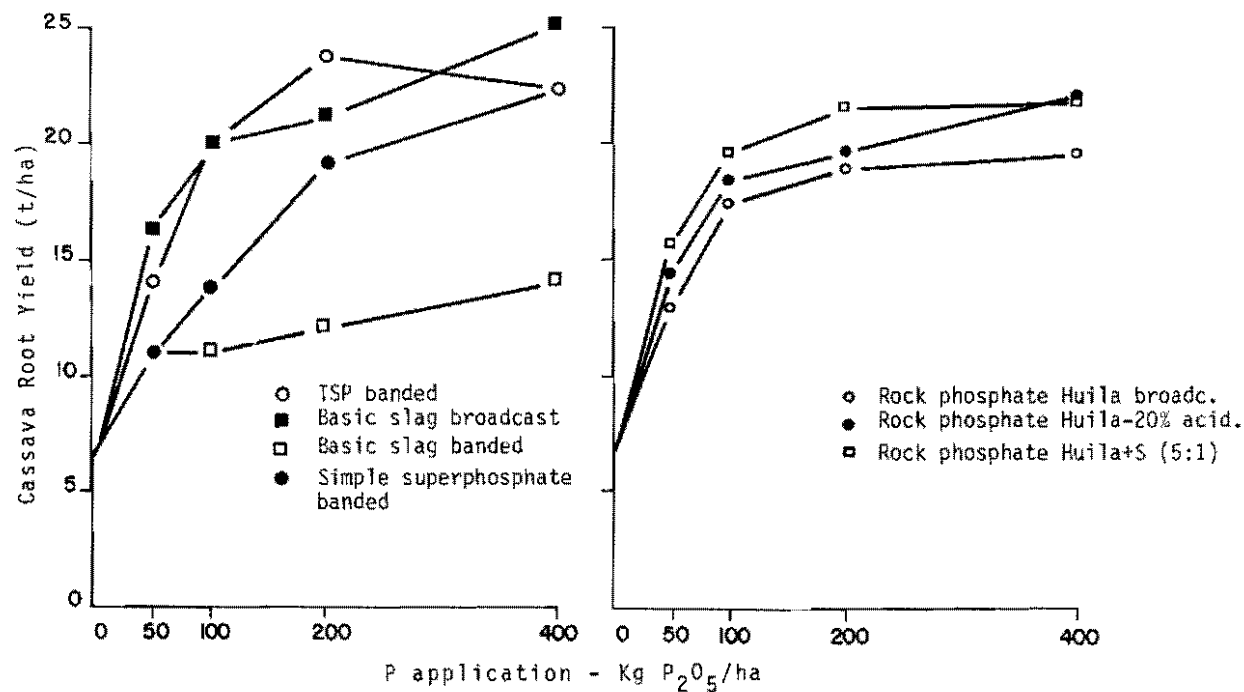
FIGURE 16. RESPONSE OF CASSAVA, cv. LLANERA, TO APPLICATION OF DIFFERENT LEVELS AND SOURCES OF P IN CARIMAGUA.
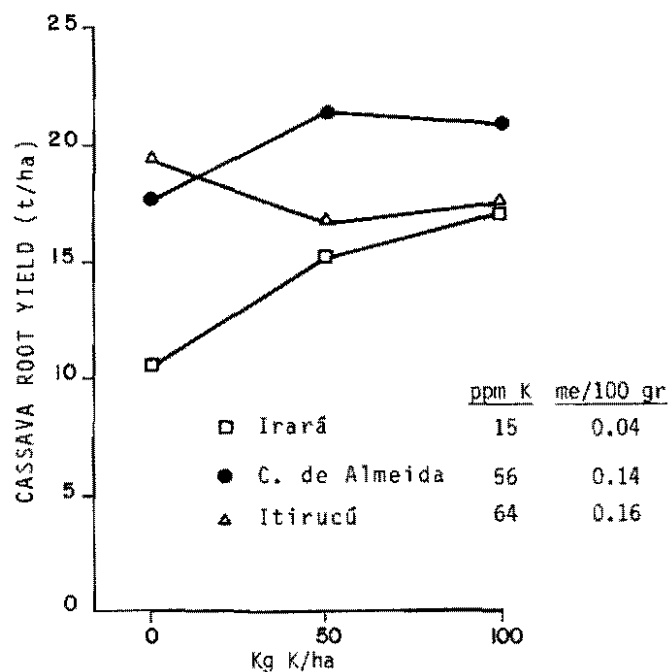
FIGURE 17.  RESPONSE OF CASSAVA TO K APPLICATION IN
THREE BRASILIAN SOILS OF VARYING EXCHAN-
GEABLE K CONTENT (Source: Gomez *et al*,
1973).
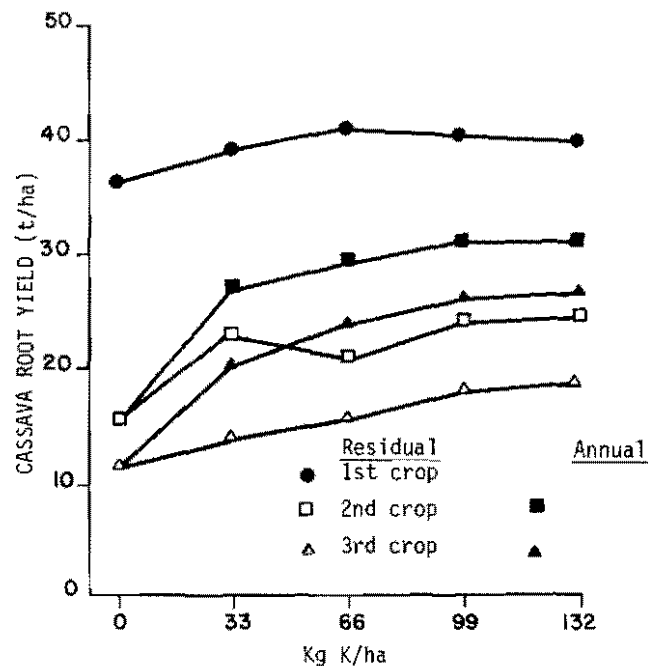
FIGURE 18.   RESPONSE OF CASSAVA TO DIFFERENT LEVELS OF
K APPLIED EITHER ONCE WITH THE FIRST CROP
(RESIDUAL EFFECT) OR ANNUALLY WITH EACH OF
THREE CONSECUTIVE CASSAVA CROPS IN CRUZ DAS
ALMAS, BAHIA, BRAZIL.
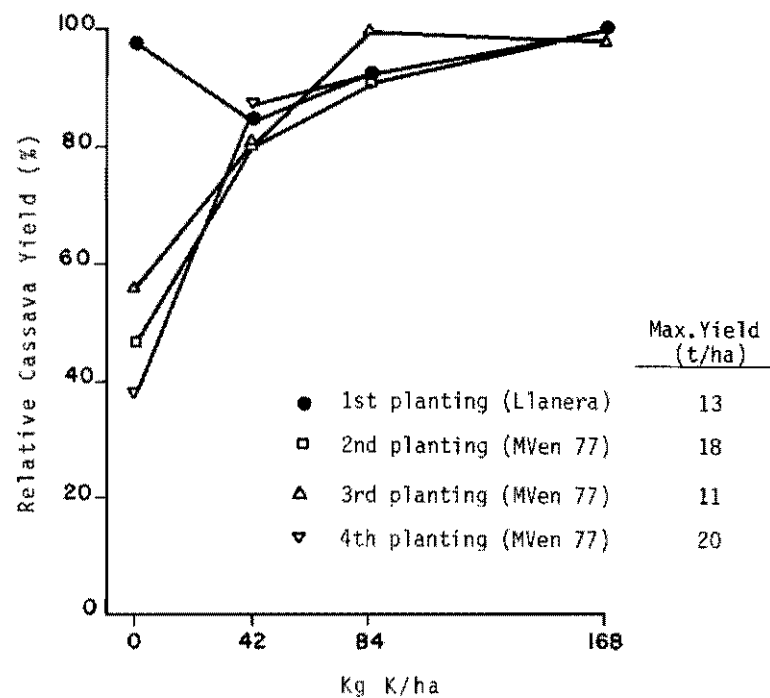
FIGURE 19.   RESPONSE OF FOUR CONSECUTIVE CASSAVA CROPS TO
THE ANNUAL APPLICATION OF DIFFERENT LEVELS OF
K IN CARIMAGUA.
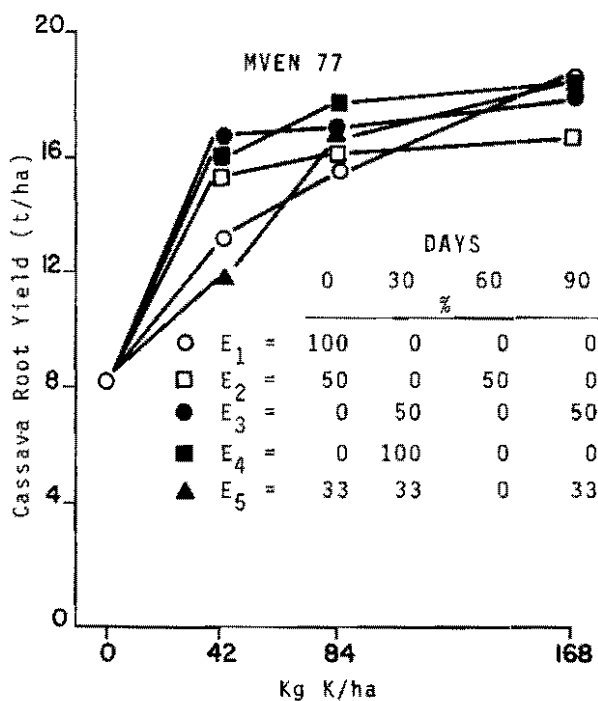
FIGURE 20. EFFECT OF DIFFERENT LEVELS AND TIME OF
APPLICATION OF K ON ROOT YIELD OF CASSAVA
MVen 77 IN CARIMAGUA
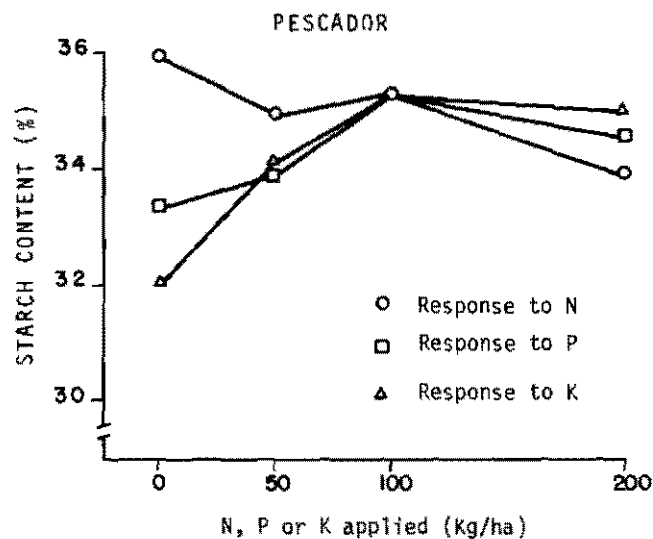
FIGURE 21. EFFECT OF DIFFERENT LEVELS OF APPLIED N,P, OR K ON THE STARCH CONTENT OF CASSAVA ROOTS IN PESCADOR, CAUCA.
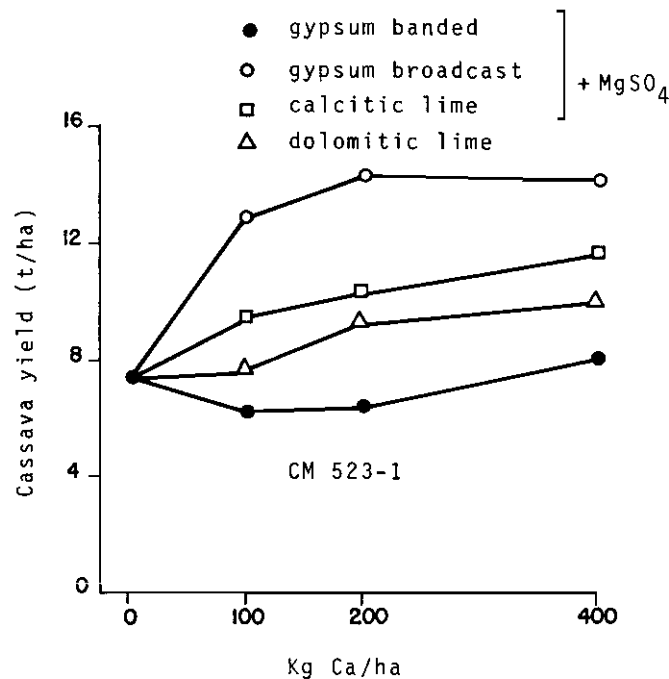
FIGURE 22. THE EFFECT OF DIFFERENT LEVELS, SOURCES AND METHODS OF APPLICATION OF Ca ON ROOT YIELD OF CASSAVA, CM 523-1, IN CARIMAGUA.
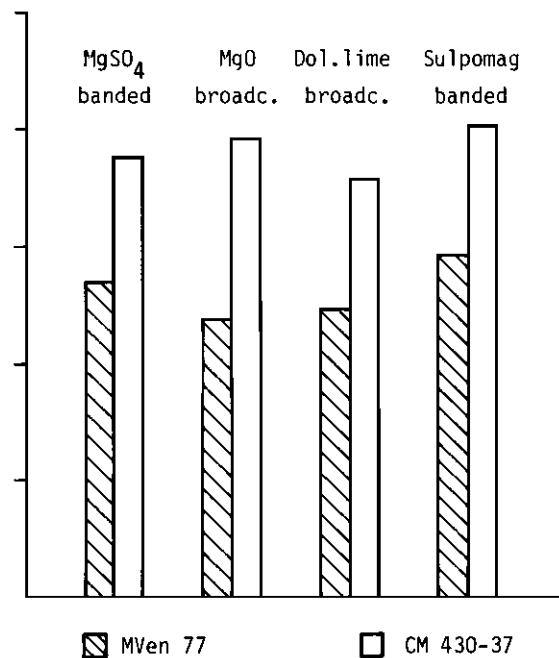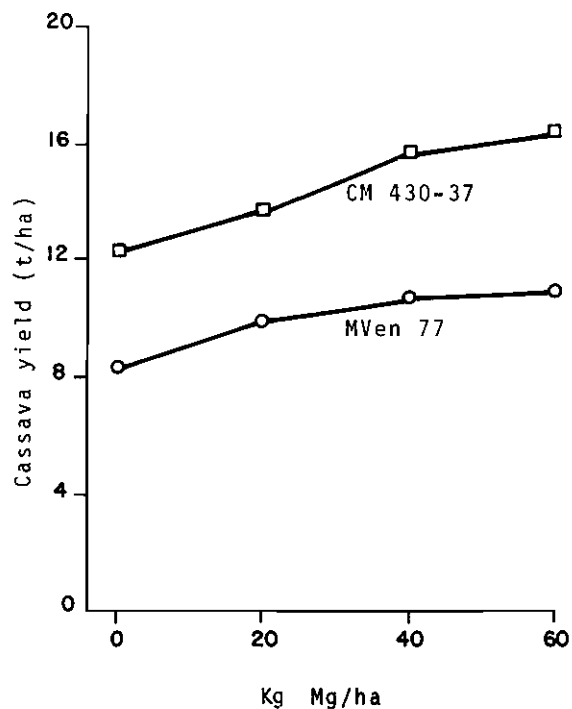
FIGURE 23. RESPONSE OF TWO CASSAVA VARIETIES TO DIFFERENT LEVELS (LEFT) AND SOURCES (RIGHT) OF APPLIED Mg IN CARIMAGUA
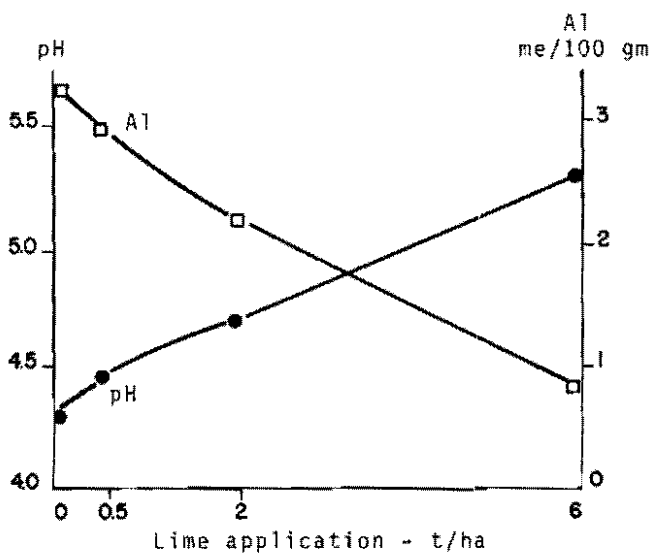
FIGURE 24.  THE EFFECT OF LIME APPLICATION ON SOIL
pH AND EXCHANGEABLE Al-CONTENT IN CARI-
MAGUA
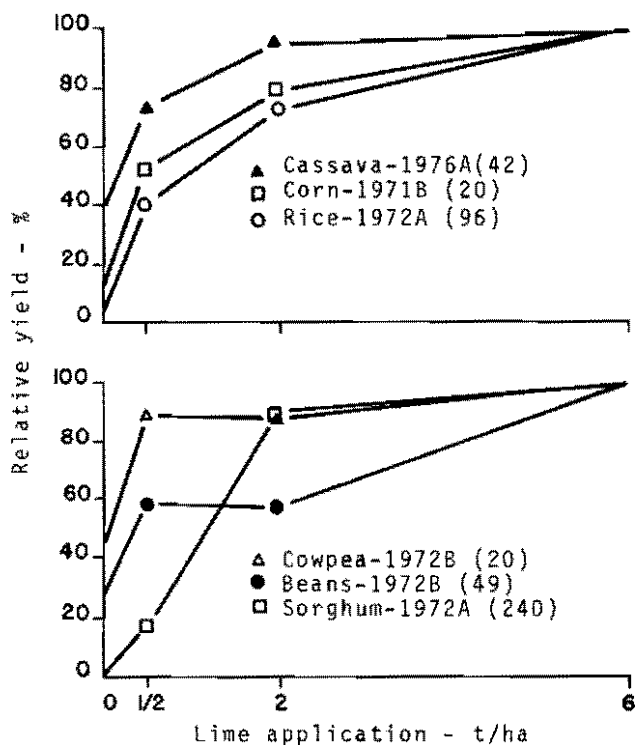
FIGURE 25.    THE EFFECT OF DIFFERENT LEVEL OF APPLIED
LIME ON THE RELATIVE YIELD OF SIX CROPS
GROWN IN CARIMAGUA.   NUMBERS IN PARENTHE-
SIS INDICATE THE NUMBER OF VARIETIES TEST-
ED.
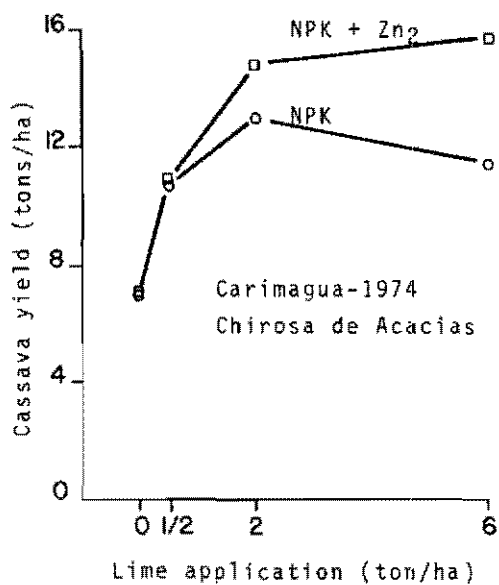
FIGURE 26. THE RESPONSE OF CASSAVA
TO LIME WITH AND WITHOUT
THE APPLICATION OF 20 Kg
/ha OF Zn.
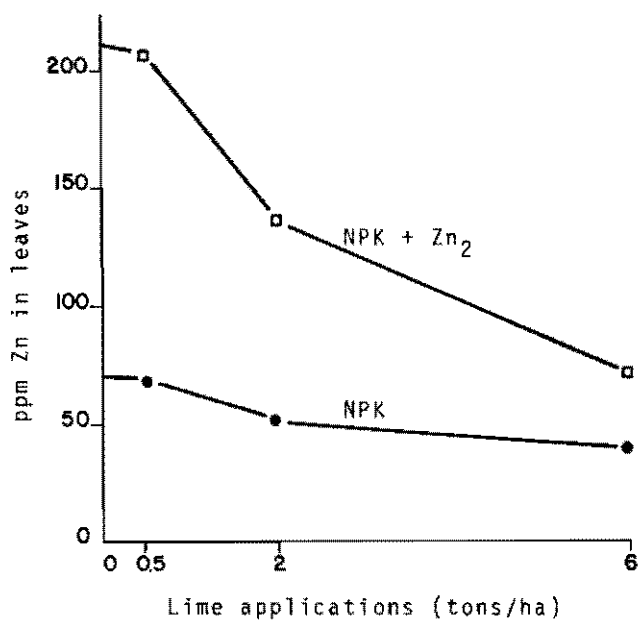
FIGURE 27. THE EFFECT OF LIMING ON THE Zn
CONTENT OF CASSAVA LEAVES AT 2
MONTHS OF AGE, WITH AND WITHOUT
SOIL APPLIED Zn.
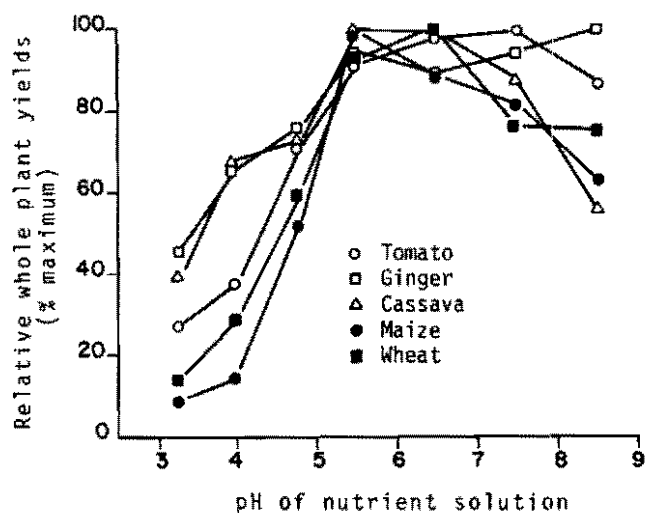
FIGURE 28.  RESPONSE OF PLANTS TO A SERIES OF
CONSTANT pH VALUES IN NUTRIENT SO-
LUTION (Islam, 1979).
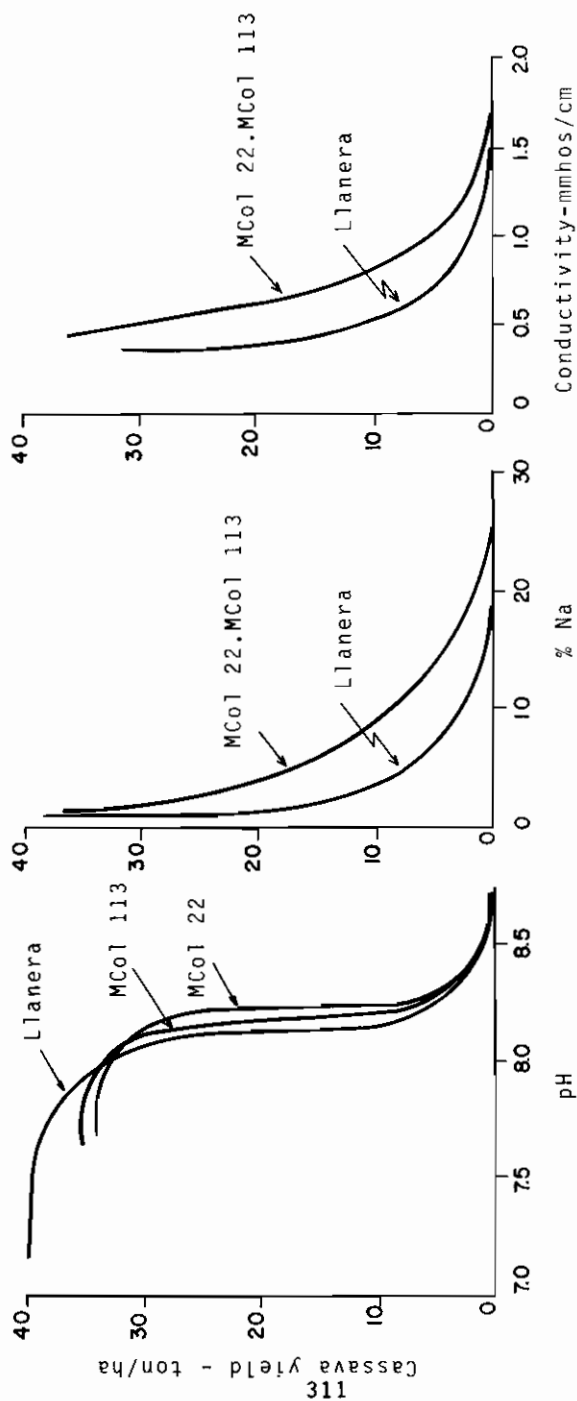
FIGURE 29. RELATION BETWEEN THE ROOT YIELD OF THREE CASSAVA VARIETIES AND SOIL pH, PERCENT Na SATURATION AND SATURATED SOIL SOLUTION CONDUCTIVITY IN A SALINE-ALKALINE FIELD IN CIAT-PALMIRA

311
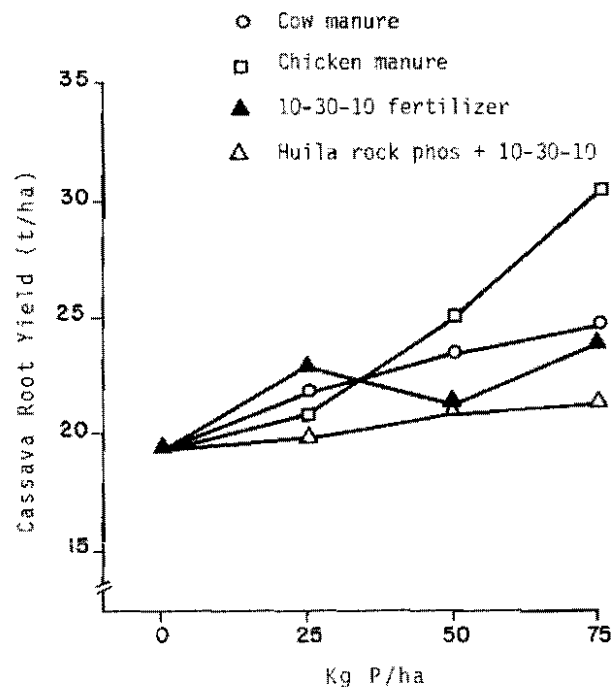
FIGURE 30. CASSAVA RESPONSE TO DIFFERENT LEVELS OF P
APPLIED AS VARIOUS ORGANIC OR INORGANIC
FERTILIZERS IN MONDOMO, CAUCA.
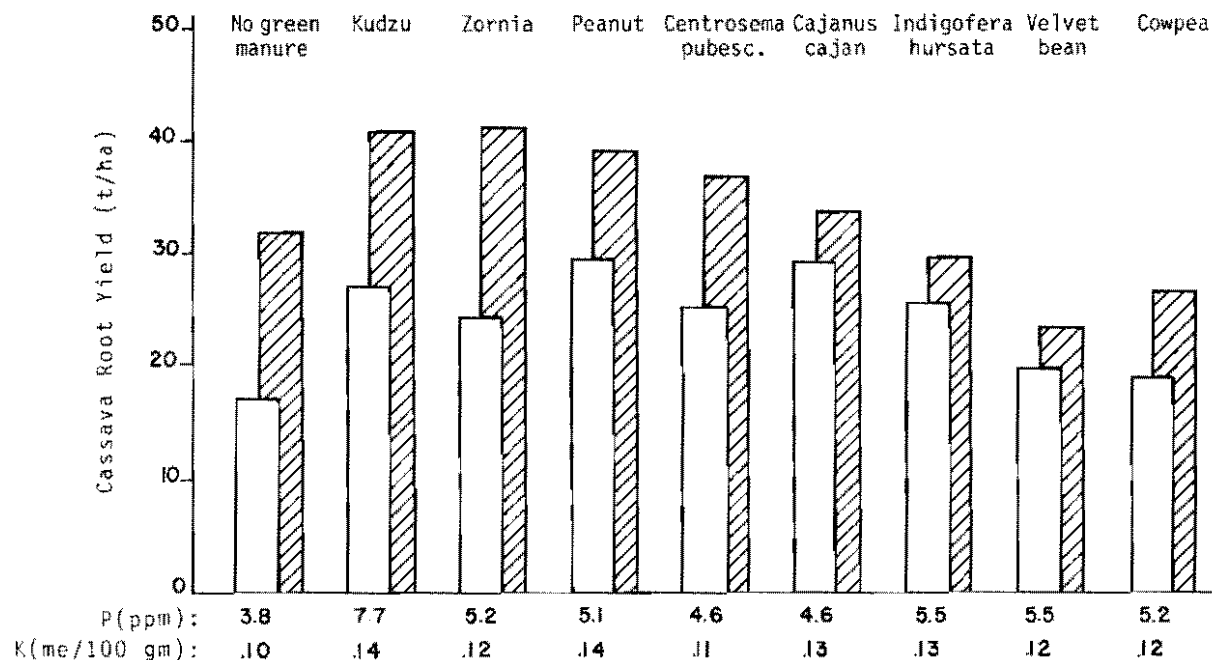
FIGURE 31. RESPONSE OF CASSAVA, MCol 1684, TO INCORPORATION OF SEVERAL GREEN MANURES BOTH IN THE ABSENCE(OPEN BARS) AND IN THE PRESENCE OF 500 Kg/ha OF 10-30-10 (STRIPED BARS). NUMBERS BELOW THE BARS INDICATE THE AVAILABLE P AND EXCHANGEABLE K CONTENTS OF THE SOIL BEFORE PLANTING CASSAVA IN QUILICHAO.
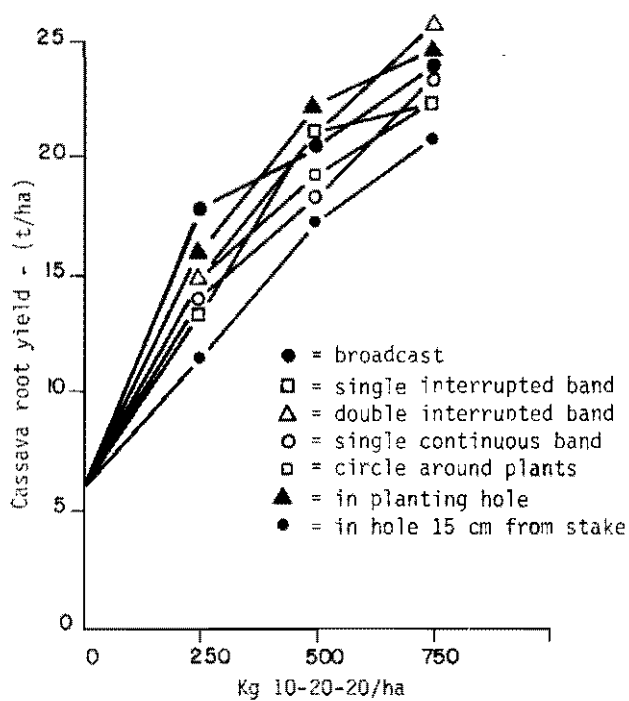
FIGURE 32. CASSAVA RESPONSE TO DIFFERENT LEVELS
AND METHODS OF APPLICATION OF 10-20-20
FERTILIZERS IN CARIMAGUA

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# FUNCTION OF VESICULAR-ARBUSCULAR MYCORRIZA FOR CASSAVA

## GROWTH

Ewald Sieverding*
Reinhardt H. Howeler

## INTRODUCTION

In Latin America, cassava is generally grown in acid soils of low fertility. In these soils phosphorus (P) is the most limiting element for plant nutrition (Howeler, 1980). In contrast to other crops as maize, beans, cowpea and rice, cassava has a very low external P requirement in the field. However, grown in nutrient solution, cassava has one of the highest external P requirements in comparison to other crops (Howeler, 1983). These differences have been mainly explained by the fact that cassava roots are associated by mycorrhizal fungi in the field, whereas in nutrient solution mycorrhizal associations generally do not occur.

## THE MYCORRHIZAL SYMBIOSIS

Botanically, mycorrhiza is the symbiotic mutualistic association between roots of plants and soil born fungi. The most important mycorrhizal formation is considered to be the vesicular arbuscular mycorrhiza (VAM) which can be observed in the roots after a staining procedure of the fungus (Phillips and Hayman, 1970). VAM mycorrhiza is characterized by*formation of external mycelium, vesicles and arbuscles in the cortical cells of the root as shown in Figure 1. About 95% of the world's plant species form this kind of mycorrhiza (Trappe, 1981). The soil born fungi involved belong to five genera of the family Endogonaceae, i.e. *Acaulospora*, *Entrophospora*, *Gigaspora*, *Glomus* and *Sclerocystis*. Up to the date about 120 fungal species are described. All VAM fungi are obligate symbionts and cannot be cultivated on artificial media. The fungi require

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spores

arbuscle

cortical cells of root

external mycelium

vesicle

Fungus requires 1 - 10 % of plant produced carbohydrates for it's growth

Plant yield increase of 150 - 10.000 % is possible due to improved plant nutrition
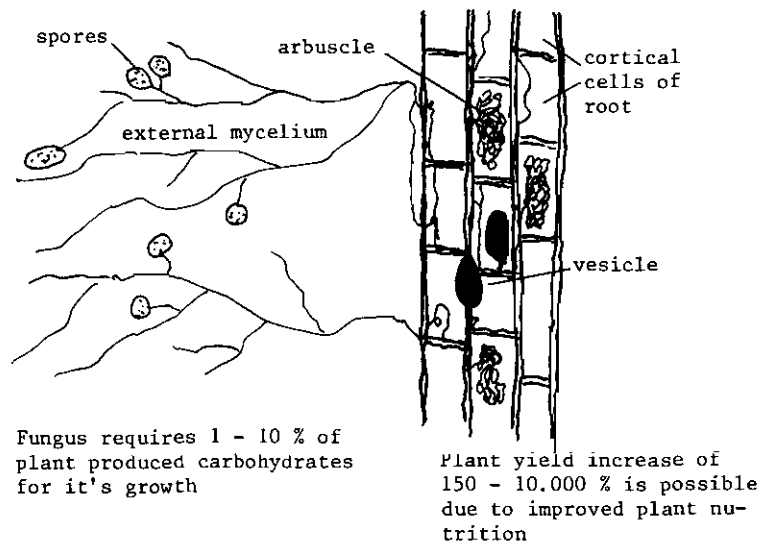
FIGURE 1.   MYCORRHIZAL FORMATION IN PLANT ROOTS

a living host plant for their reproduction.

## DISTRIBUTION OF VAM FUNGI

VAM fungi are found worldwide under all edapho-climatic conditions; however, quantity and composition of fungal species in the mycorrhizal population can vary widely among sites, as demonstrated from a small area of the hilly Mondomo region (Table 1). In areas with less variability in soils and climatic conditions, some species of VAM fungi may be found dominantly over a large area. This is the case with *Entrophospora colombiana* in the acid soils of the eastern plains of Colombia (Howeler and Sieverding, 1983, Spain, pers. comm.) or *Glomus intraradices* in most areas of India (Schenck, pers. comm.). Some fungal species are found worldwide as for example *G. fasciculatum* and *G. mosseae* whereas others are so far known only from restricted areas. In general a direct correlation between the presence of certain VAM fungi and soil classes is not found (Toro *et al*, 1985). However, some correlation may exist between the presence of certain fungal species and soil pH and other soil chemical or physical conditions. *G. mosseae*, for example, is not found in soils of pH lower 5.3 (Sieverding, pers. comm.).

## FUNCTION OF VAM FUNGI

The main function of VAM fungi consist in the growth of the fungi in or between cortical cells of the rootlets and out into the surrounding soil (Fig. 1). The fungus absorbs nutrients from the soil and translocate them to the root and receives from the host photosynthates and their derivates (Ho and Trappe, 1974). The demand of the fungi for photosyntates may be in the order of 1-10% of the plants assimilates. In general, the fungal hypha extending into the soil serve as extensions of the root system. The fungi are more effective for nutrient absorption, physiologically and geometrically than the roots themselves (Trappe, 1981). It has been demonstrated that hyphae can grow up to 8 cm from the root (Rhodes and Gerdemann, 1975). The density of the VAM hyphal network around the root can be very high with up to 80 entry points per cm root (Harley and Smith, 1983), which demonstrates the importance of VAM fungi to increase the contact between the plant roots and the substrate in which the plant grows.

## IMPORTANCE OF VAM FUNGI FOR NUTRIENT UPTAKE

The capacity of a root to take up nutrients from the soil, and the mobility of the nutrients in the soil define the absorp-

TABLE 1. OBSERVATION OF MYCORRHIZAL FUNGI (NUMBER OF SPORES/100 g DRY SOIL) IN 9 FIELDS OF THE MONDOMO AREA (CAUCA, COLOMBIA).

| Species of mycorrhizal fungi | SITE NUMBER | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1. *Acaulospora* sp. | 1035 | 352 | 198 | 1036 | 270 | 393 | 1652 | 932 | 79 |
| 2. *G. fasciculatum* | 1082 | 755 | 550 | 644 | 557 | 593 | 477 | 875 | 2665 |
| 3. *Glomus* sp. | 1 | 2 | 2 | 2 | 13 | 170 | 8 | 7 | 1 |
| 4. *Gigaspora* sp. | 5 | 8 | 1 | 29 | 29 | 2 | 31 | 9 | 6 |
| 5. Not identified A. | 1 | 0 | 1 | 0 | 0 | 0 | 3 | 1 | 1 |
| 6. *Acaulospora* sp. | 2 | 0 | 1 | 5 | 0 | 0 | 1 | 0 | 0 |
| 7. *A. appendicula* | 74 | 47 | 28 | 955 | 376 | 38 | 191 | 26 | 54 |
| 8. *G. manihotis* | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 4 |
| 9. Not identified B. | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| 10. *Gigaspora* sp. | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 0 |
| 11. *Entrophospora* sp. | 2 | 0 | 1 | 0 | 2 | 3 | 1 | 1 | 0 |
| 12. Not identified C. | 0 | 0 | 2 | 0 | 11 | 0 | 0 | 1 | 0 |
| 13. *A. foveata* | 2 | 2 | 1 | 2 | 1 | 6 | 3 | 0 | 3 |
| TOTAL | 2204 | 1166 | 788 | 2674 | 1262 | 1205 | 2368 | 1853 | 2813 |

tion of nutrients by plants (Bowen, 1980). The absorption rate of ions of high mobility in the soil (like $NO_3$) is determined by the plant species or variety. The absorption of ions of low mobility (like P, Zn, Cu, Mo, and to lesser extent K, S, $NH_4^+$) depends on the root density per soil volume. In this latter case, the morphology of the plant root and the growth rate of VAM fungi in the soil are determining the rate of nutrient absorption. Several workers (reviewed by Harley and Smith, 1983) have clearly demonstrated that VAM fungi are not able to absorb other nutrient sources from soil than those which are normally available for the plant root. Thus, VAM fungi increase only the efficiency of the plant in nutrient absorption.

One of the elements with very low diffusion rates in the soil is phosphorus. The soil solution contains relatively low concentrations of P and around roots the soil is very rapidly depleted of this element. The function of VAM fungal hyphae is obvious; by growing into the undepleted soil, P is absorbed from a greater soil volume. Direct P uptake and transport to the root via hyphae has been demonstrated in studies using P32. The P inflow to a mycorrhizal root can be 3 to 4 times higher than to a non-mycorrhizal root. Also, the P inflow rate increases with increasing root infection by VAM fungi (Harley and Smith, 1983).

Other nutrients such as Zn, Cu, S, B, Mo and some heavy metals also have been demonstrated to be taken up directly by fungal hyphae and to be transported to the root.

DEPENDENCY OF CASSAVA ON VAM FUNGI

Cassava has a very coarse root system. This may be the principal reason for the high dependency of cassava on VAM fungi.

Dependency of cassava on VAM fungi in different soils is easily demonstrated in greenhouse trials where non-mycorrhizal plants are compared with mycorrhizal plants. For that, the growth of plants in unsterilized and sterilized soil from different sites is compared (Fig.2). The difference in growth between plants in sterilized soil (without mycorrhiza) and unsterilized soil (with native mycorrhizal fungi) demonstrate the dependency of cassava on VAM fungi for growth in those soils. It is also clear that even in a soil of high chemical fertility (CIAT, Palmira) cassava depends on mycorrhiza.

Dependency of cassava on mycorrhiza for P nutrition is illustrated in Figure 3. To the soil, increasing P levels were added and plants were grown with or without the VAM fungus *Glomus manihotis*. Obviously, inoculation with mycorrhizal fungi can be substituted by very high P applications. On the other
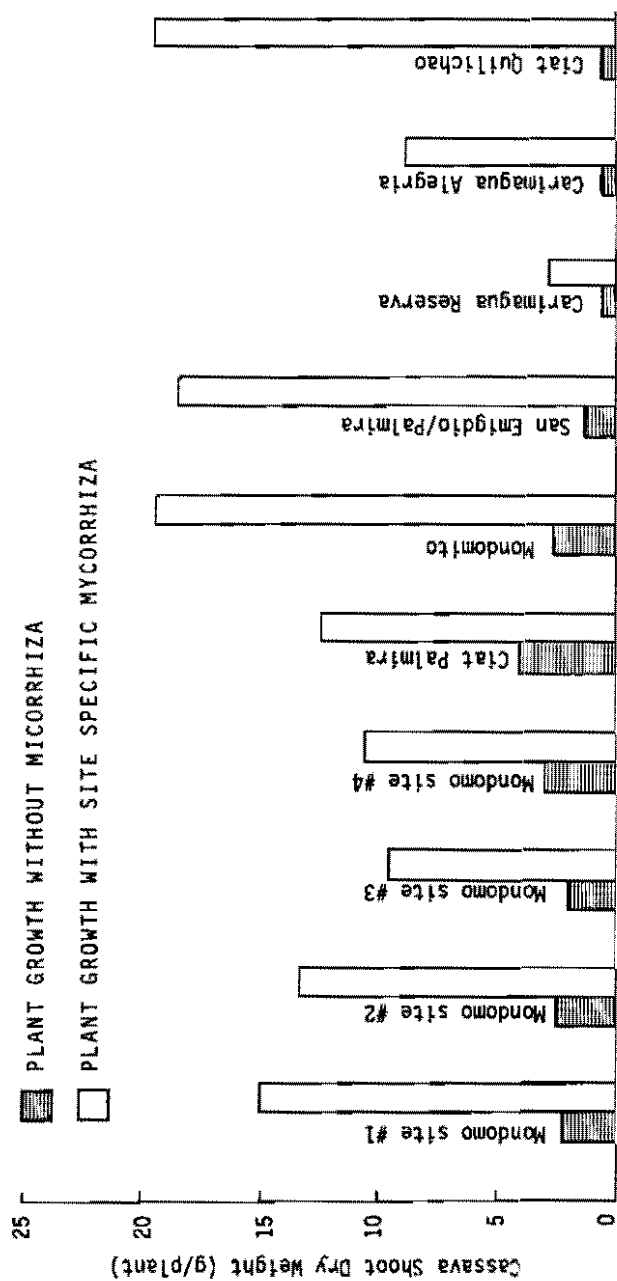
FIGURE 2. DEPENDENCY OF CASSAVA GROWTH ON SITE SPECIFIC MYCORRHIZA OF DIFFERENT LOCATIONS
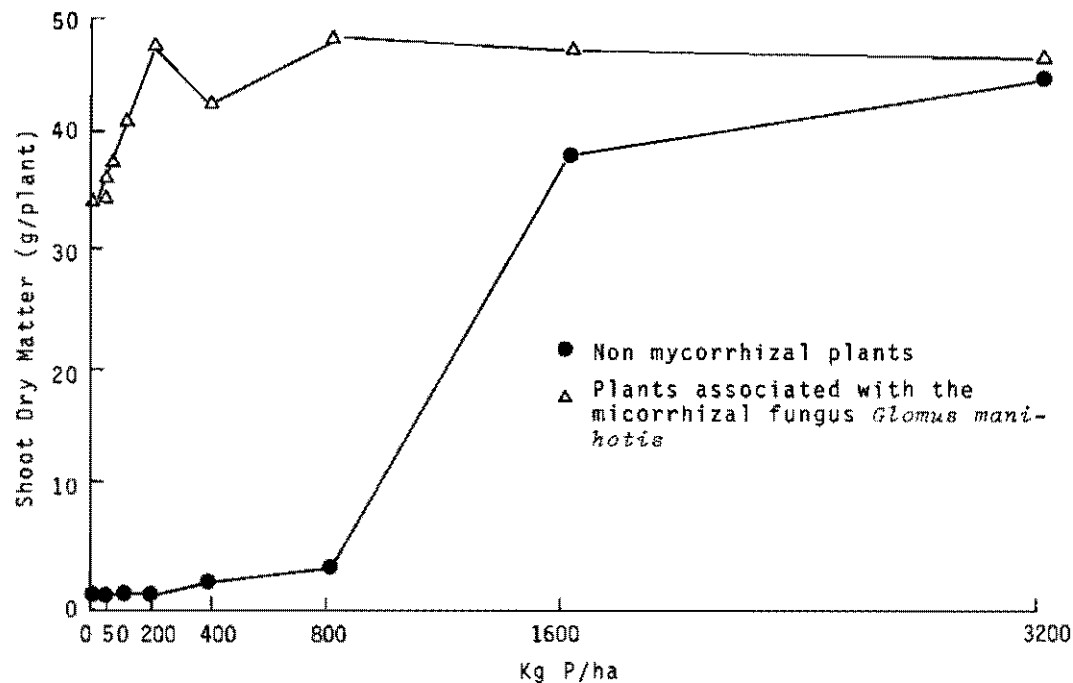
FIGURE 3. EFFECT OF INOCULATING CASSAVA CV. MMEX 59 WITH *Glomus manihotis* ON GROWTH AT DIFFERENT LEVELS OF P APPLICATION, IN SOIL FROM CIAT, QUILICHAO.

hand, mycorrhizal plants responded only to a limited level of P
application (in this trial: 200 Kg P/ha). No response to higher
P applications have been explained by negative effects fo high
P level on the development and activity of VAM fungi.

Dependency of cassava on VAM fungi was also shown in field
trials (Howeler *et al*, 1982; Howeler and Sieverding, 1983). Af-
ter sterilization of field plots with methyl bromide which erra-
dicated the native VAM fungi, cassava growth was inhibited dur-
ing the first five months in comparison to growth of cassava
plants in unsterilized neighbouring field. In sterilized soil,
plants had typical symptoms of P deficiency, indicating the lack
of mycorrhizal association. Some plants died in drought stress
during the dry seaseon. At three months plant height in steril-
ized plots was about 30-40 cm, while that in unsterilized plots
was 100-120 cm. After 5 months, plants in the sterilized plots
started to recuperate, first along plot borders and later also
in the center. From this it was concluded that native mycorrhi-
zal fungi had invaded the sterilized plots. At harvest yields
of the two tested cassava cultivars were lower in the steriliz-
ed than in the unsterilized plots (Table 2). These data shows
that exclusion of mycorrhizal association during a period of
growth reduces cassava yields considerably.

DIFFERENT EFFECTIVENESS OF SPECIES OF VAM FUNGI

In greenhouse trials it can be demonstrated that isolated
species of VAM fungi differ considerably in their effectiveness
to increase cassava growth. For that, rooted plantlets of cas-
sava (for methodology of producing such plantlets see: Cock *et
al*, 1981) are planted in pasteurized soil and inoculated with
different fungal species. In trials of this kind, the inoculum
is placed under the roots. As inoculum can serve fungal spores,
infected roots of a host plant, or a soil substrate in which the
fungal species had been multiplied. The latter source of inocu-
lum is frequently used resulting in a rapid colonization of the
cassava roots with VAM fungi. Table 3 shows the effectiveness
of different species of VAM fungi for increasing shoot growth,
P uptake and length of rootlets of cassava.

Among species and isolates of VAM fungi differences exist
in their ability to complete with the indigenous VAM fungal po-
pulations, as shown in Figure 4. Cassava plantlets were grown
in soil with high (CIAT, Quilichao) or low (Carimagua, Alegria)
populations of native VAM fungi, and inoculated with different
isolates of VAM fungi. In both soils, *G. manihotis* (CIAT isola-
te C-I-I) and *E. colombiana* (C-10) were superior than the native
population; in soil from Carimagua-Alegria, also *A.mellea* (C-
15-2) completed well with the indigenous mycorrhiza and increas-
ed yields. It can be concluded that only few species of VAM
fungi are generally superior that the indigenous mycorrhizal

328
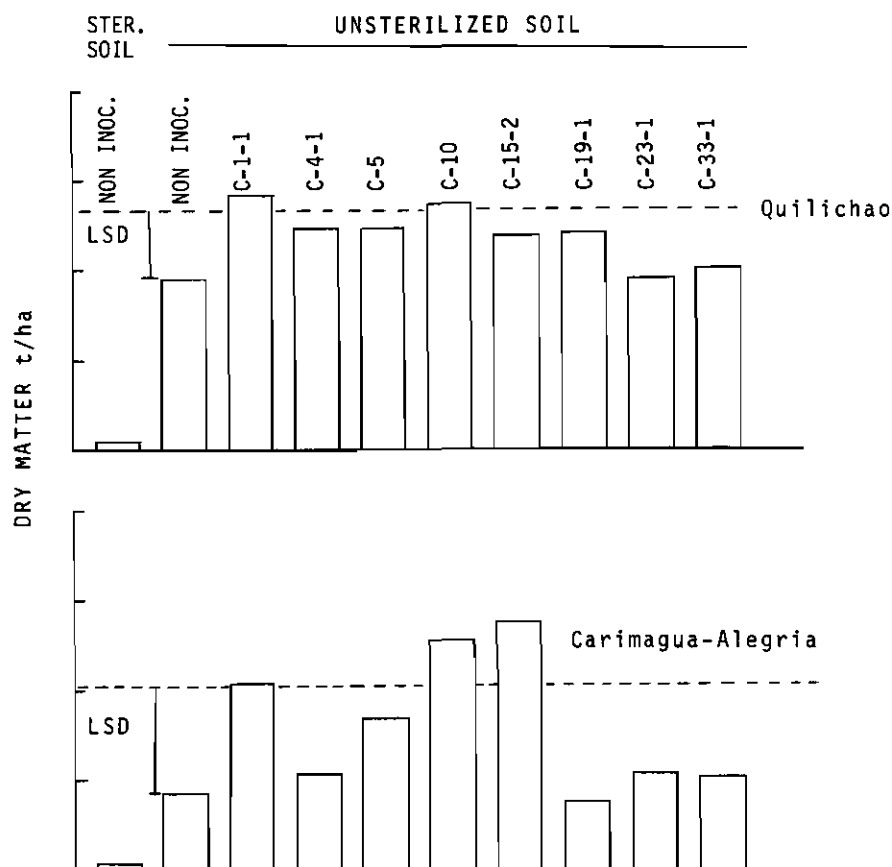
FIGURE 4. EFFECT OF INOCULATION WITH VARIOUS MYCORRHIZAL ISOLA-
TES ON DM PRODUCTION OF THREE MONTH OLD CASSAVA, MVEN
77, GROWN IN TWO UNSTERILIZED SOILS, COMPARED WITH
THE NON-INOCULATED CHECKS IN STERILIZED AND UNSTERILIZ-
ED SOILS IN THE GREENHOUSE.
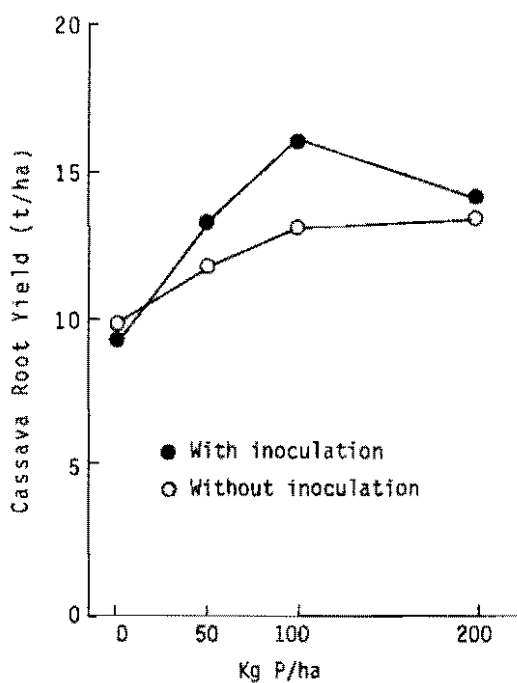
FIGURE 5.   EFFECT OF VARIOUS LEVELS OF P AS WELL AS
            INOCULATION ON ROOT YIELD OF CASSAVA,
            CULTIVAR MVEN 77 IN CARIMAGUA

TABLE 2.  EFFECT OF SOIL STERILIZATION IN THE FIELD ON CASSAVA
          YIELDS (t/ha)

| Treatment | Cassava cultivar* | |
| | MCol 638 | MCol 1684 |
| --- | --- | --- |
| Sterilized soil | 19.6b | 32.5b |
| Unsterilized soil | 41.3a | 53.1a |

Numbers within the same column followed with different
letter are significantly different at P=0.05

fungi.  These superior fungal species have to be identified in
screening trials before utilization in field trials.

CASSAVA FIELD INOCULATION WITH VAM FUNGI

On the average of 19 field trials, cassava yields were in-
creased by 24% due to inoculation with selected VAM fungi, as
summarized in Table 4.  At those indicated sites, inoculum was
applied under the cassava stakes or under the stakes and in
side bands.  Inoculum consisted of soil substrate infested with
one or two isolates of VAM fungi.  Different P levels and P
sources were applied in these trials.  As also shown in Figure
5, in acid, low P soils, response to field inoculation is only
obtained when inoculation is combined with P application.

SOURCES OF INOCULUM AND METHODS OF FIELD INOCULATION

For field inoculation it is most convenient to use a soil
substrate in which a fungal species has been multiplied on a
host.  For obtaining inoculum, a proper soil is first desinfect-
ed (CIAT, 1985b) to erradicate the indigenous mycorrhizal popu-
lation as well as pathogenic fungi and other harmful soil inha-
bitants.  Then, the soil is inoculated with a small amount of
a pure culture of a selected fungus.  A host (like maize or a
forage plant) is planted; this host will multiply the fungus
in about 3-6 months.  The soil with the roots of the host plant

TABLE 3.   EVALUATION OF MYCORRHIZAL ISOLATES FOR EFFECTIVITY
           ON CASSAVA

| Isolate Number | Species | Effectivity for | | |
|---|---|---|---|---|
| | | Plant growth | P uptake | Root length |
| C-1-1 | *G. manihotis* | xxx | xxx | xx |
| C-3-3 | *G. geosporum* | xx | xx | xx |
| C-3-7 | *Gi. pellucida* | 0 | 0 | x |
| C-11-2 | *E. colombiana* | xxx | xxx | xxx |
| C-13-1 | *A. appendicula* | xxx | xxx | xx |
| C-14 | *A. morrowae* | 0 | 0 | 0 |
| C-15-1/2 | *A. mellea* | xx | xx | xxx |
| C-28-5 | *A. longula* | x | x | xxx |
| C-76-1 | *A. scrobiculata* | 0 | 0 | xx |

0      Not effective
x      Low effectivity
xx     Moderate effectivity
xxx    High effectivity

TABLE 4.  EFFECT OF FIELD INOCULATION WITH SELECTED MYCORRHIZAL STRAINS ON CASSAVA
FRESH ROOT YIELDS (t/ha) AFTER ONE YEAR OF GROWTH AT DIFFERENT SOIL SITES
WITH THE APPLICATION OF DIFFERENT SOURCES AND LEVELS OF P FERTILIZER (MEANS
OF FOUR REPLICATIONS AT EACH SITE).  SOURCE: CIAT ANNUAL REPORTS FOR 1982,
1983; CASSAVA PROGRAM.

| Soil sites* | Source level P** | P (kg/ha) | Root Yields-t/ha | | Most effective mycorrhizal isolate number |
| | | | No. inocul. | Inocul. | |
| --- | --- | --- | --- | --- | --- |
| Mondomito I | | 0 | 26.1 | 27.3 | C-4-2 |
| Carimagua-Yopare | | 0 | 9.3 | 9.3 | C-1-1 |
| Mondomito I | TSP | 50 | 29.9 | 36.7 | C-19-1 |
| Mondomito II | TSP | 50 | 7.0 | 8.2 | C-33-1 |
| Agua Blanca I | TSP | 50 | 13.1 | 18.1 | C-1-1 |
| Pescador | TSP | 50 | 18.5 | 22.9 | C-1-1 |
| Carimagua-Alegria | TSP | 50 | 15.9 | 18.3 | C-19-1 |
| Carimagua-Alegria | TSP | 100 | 16.4 | 19.9 | C-4-2 |
| Carimagua-Yopare | TSP | 100 | 11.6 | 17.6 | C-1-1 |
| Carimagua-Alegria | BS | 50 | 18.0 | 18.6 | C-10 |
| Mondomito II | HRP | 50 | 6.2 | 9.5 | C-10 |
| Agua Blanca I | HRP | 50 | 12.9 | 16.1 | C-1-1 |
| Agua Blanca II | HRP | 50 | 21.2 | 27.1 | C-1-1/C-10 |
| Agua Blanca III | HRP | 50 | 15.6 | 18.3 | C-1-1/C-10 |
| Agua Blanca IV | HRP | 50 | 24.7 | 31.1 | C-3-5 |
| Tres Quebradas | HRP | 50 | 17.7 | 19.1 | C-1-1/C-10 |
| Pescador | HRP | 50 | 11.3 | 20.4 | C-33-1 |
| Carimagua-Alegria | HRP | 50 | 15.9 | 19.8 | C-10 |
| Carimagua-Yopare | HRP | 100 | 11.7 | 19.2 | C-1-1 |

*   Carimagua sites are Oxisols; all others are Inceptisols

**  TSP: Triple superphosphate
    BS : Basic slag
    HRP: Huila rock phosphate.

is used as inoculum after chopping up the material. If possible the inoculum should be used fresh. Little is known about how long field inoculum can be stored without risk of losing infection potential.

At CIAT, in general, inoculum was applied in amounts of 100 to 400 g per cassava plant which correspond with 1 to 6 t of inoculum/ha, depending on the planting density. Even though a general recommendation for inoculum amount cannot yet be given, the inoculation technique should make sure that the first sprouting cassava roots will pass through the inoculum. In this way the roots become infected with the introduced fungus and the ability of the inoculated fungus to compete with the indigenous mycorrhiza will increase (Sieverding, 1985). Double inoculation, i.e. placing inoculum under the stakes at planting and in short bands to the side of the plants several months later may be superior over single inoculation (Table 5).

RESEARCH REQUIRED FOR INOCULATING CASSAVA WITH VAM FUNGI IN THE

FIELD

The necessary activities before practical use of inoculation technology with effective VAM fungi are demonstrated in a flow diagram (Fig. 6). Four principal blocks of activities may be distinguished:

a. Collection, isolation and maintenance of VAM fungal isolates.

b. Screening procedures of mycorrhizal isolates in the greenhouse.

c. Inoculum production and application techniques, as well as field adaptation trials in different edapho-climatic zones.

d. Transfer of the technology

Collection, Isolation and Maintenance of VAM Fungal Isolates

A large "germplasm-bank" of VAM fungi is a basic requirement for screening procedures. The "germplasm-bank" should include isolates of the Endogonaceae family from all edaphoclimatic conditions of a country. For research, each institution will have to develop its own appropriate methods for the routine work of isolation and maintenance of fungal isolates. This includes the selection of easily manageable materials for all procedures (CIAT, 1982). Large numbers of VAM isolates are difficult to handle on living hosts; thus, they should be stored
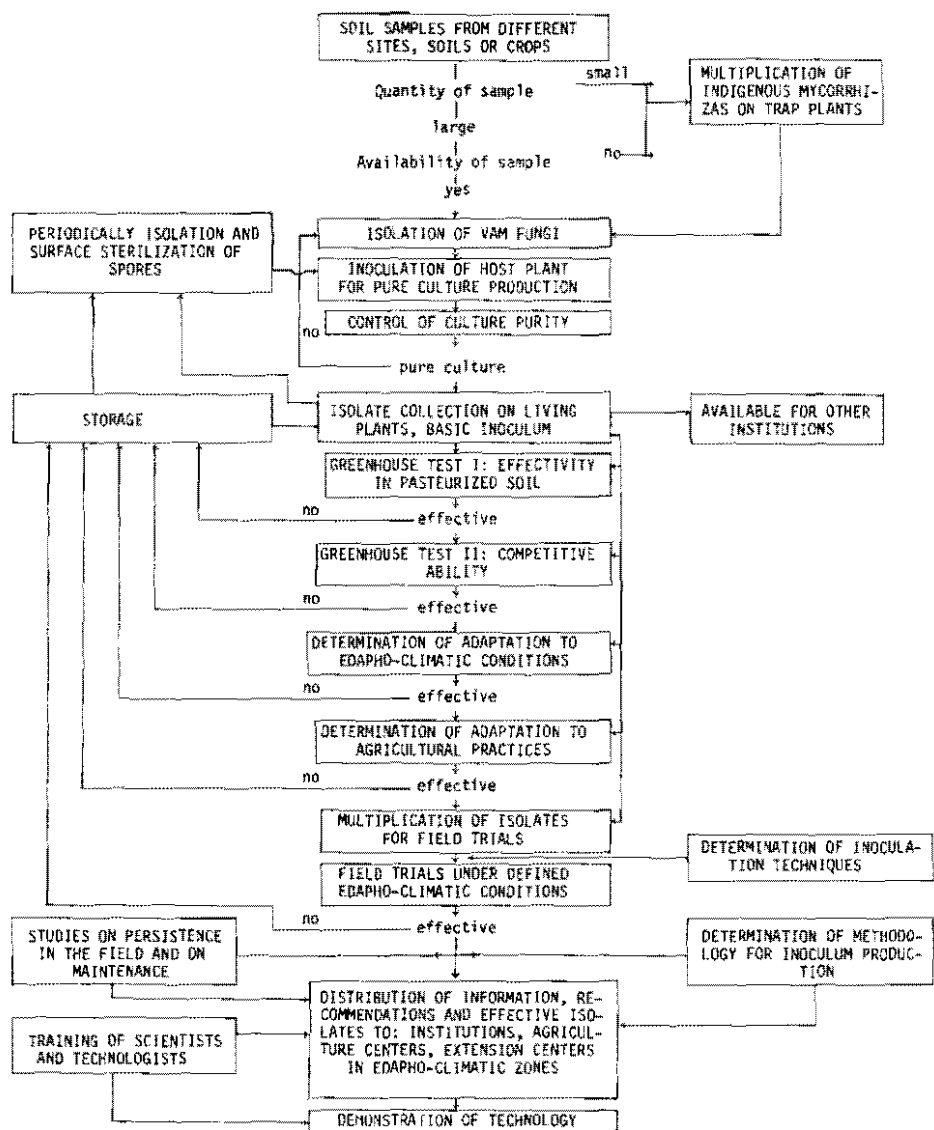
FIGURE 6. FLOW DIAGRAM FOR MYCORRHIZA RESEARCH IN THE STRATEGY OF MANAGING MYCORRHIZAL FUNGI BY FIELD INOCULATION

TABLE 5. EFFECT OF INOCULUM PLACEMENT METHOD ON CASSAVA FRESH ROOT YIELDS

| Method of inoculum placement | Fresh root yields (t/ha) | | | Mean ($\pm$ s.d.) |
|---|---|---|---|---|
| | Agua Blanca[x] | Telecom | Tres Quebradas | |
| Not inoculated | 15.6 | 13.5 | 17.7 | 15.6 $\pm$ 2.1 |
| Under stakes, all at planting | 17.6 | 16.9 | 15.7 | 16.7 $\pm$ 1.0 |
| Half under stakes at planting and half in side bands, 4 MAP[y] | 18.3 | 21.0 | 19.1 | 19.5 $\pm$ 1.4 |
| In side bands, all at planting | 16.8 | --[z] | -- | --- |
| In side bands, half at planting, half 4 MAP | -- | -- | 17.5 | --- |
| In side bands, all at 4 MAP | 14.1 | -- | -- | --- |
| LSD 5% | NS | 5.6 | NS | |

x At 8 MAP a severe attack by anthracnose occurred in some replications, independent of the inoculum treatment (means of 8 replications are presented)

y MAP: Months after planting

z Treatments werenot conducted at those sites

properly (CIAT, 1985a).

## Screening Procedures in the Greenhouse

The characterization of VAM fungal isolates should start under conditions without competition with indigenous VAM fungi or other soil microorganisms. Isolates should be characterized for their effectiveness to enhance growth and P uptake of cassava as well as whether they are able to occupy a large areas of the root system. This may give an indication whether the isolate is able to compete with other root occupying microorganisms. The most effective isolates should be tested in the next evaluation step. This should be conducted under soil conditions where the isolates have to compete with differing quantities and qualities of indigenous VAM fungi. Screening trials with the most effective fungi for different soil P levels, to soil temperature and water stress may follow when cassava is grown in variable edapho-climatic conditions. Of all trials, the tests for efficient P uptake and ability to compete with the indigenous mycorrhizal fungi are considered the most importants.

## Research Related to Field Inoculation

Inoculum production and application at low cost is important (CIAT, 1985b). Field inoculation trials should be conducted in all edapho-climatic zones. If it is not known how to manage the introduced fungi after inoculation, all normal agronomic practices should be applied to cassava, i.e. normally recommended fertilization, plant protection methods, etc. At the end of each trial, the VAM fungal population should be observed to find out whether the introduced fungus persisted in the field or not. Economical evaluations of the trials are necessary to decide whether, with the applied methodology, field inoculation in a given soil is worthwhile.

## Transfer of the Technology

To make sure of the transfer of the VAM technology to the farmer on a long term basis, the training of scientists is considered the only successful method. Demonstration trials should be mounted by extension workers to explain the technology to the farmer. Transfer of technology to the farmer will be possible only if inoculum production is asured.

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# CHAPTER IV

## PESTS AND DISEASES

CASSAVA PEST AND THEIR CONTROL

THE MEALYBUG AND CASSAVA GREEN SPIDER MITE COMPLEX
IN THE AMERICAS: PROBLEMS OF AN POTENTIAL FOR BIO-
LOGICAL CONTROL.

THE POTENTIAL OF HOST PLANT RESISTANCE IN CASSAVA
FOR CONTROL OF MITES AND MEALYBUGS

RECENT ADVANCES IN RESISTANCE TO INSECT AND MITE
PESTS OF CASSAVA.

CASSAVA DISEASES AND THEIR CONTROL

CASSAVA/ECOSYSTEM RELATIONSHIPS AND THEIR INFLUENCE
ON BREEDING STRATEGY.

BACTERIAL BLIGHT OF CASSAVA

*ERWINIA CAROTOVORA* VAR. *CAROTOVORA*, CAUSAL AGENT OF
BACTERIAL STEM ROT OF CASSAVA.

CASSAVA BACTERIAL LEAF SPOT

ANTHOLYSIS IN CASSAVA (*Manihot esculenta* Crantz)
POSSIBLY CAUSED BY MYCOPLASMA-LIKE ORGANISMS.


CASSAVA VIROLOGY


FUNGAL DISEASES


THE THREAT OF INTRODUCING CASSAVA DISEASES AND PEST
ON PROPAGATION MATERIAL


PATHOLOGICAL PROBLEMS OF CASSAVA (*Manihot esculenta*
Crantz) DISSEMINATED BY SEXUAL OR ASEXUAL PROPAGATED
MATERIAL.


A COMPREHENSIVE BREEDING APPROACH TO PEST AND DISEASE
PROBLEMS OF CASSAVA


INTEGRATED CONTROL OF DISEASES AND PESTS OF CASSAVA.


PRODUCTION OF CASSAVA PLANTING MATERIAL


CASSAVA QUARANTINE


THE STABILITY OF PERFORMANCE OF CASSAVA GENOTYPES

# CASSAVA PESTS AND THEIR CONTROL

Anthony C. Bellotti*
Aart Van Schoonhoven

## INTRODUCTION

Cassava ( *Manihot esculenta* ), a major energy source for 300 to 500 million people, is grown throughout the tropical regions of the world.  It is cultivated mainly in developing countries on small farms with little technology.  As a result, it has received limted attention from scientists and technologists.  FAO estimates fro 1977 indicate an annual global production of 105 million tons on 11 million hectares, of which at least 55 million are consumed by humans.  Although cassava is now cultivated in some 90 countries, 80 percent of the world's production comes from only 10; the six leading producers are Brazil (31%), Indonesia, Zaire, Nigeria, Thailand and India.  In many parts of the world, especially west Africa, cassava appears to be the most economical, lowest risk subsistence crop for the small farmer.

The increasing world population and the limited availability of energy has prompted a recent surge of interest in cassava, not only for traditional uses as a human food and for a specialized starches including tapioca but also for animal feedstuffs and industrial uses.  There is an excellent potential for increasing both yield and area under cultivation.  Two international centers for tropical agriculture, one in Colombia (Centro Internacional de Agricultura Tropical, CIAT), and another in Nigeria (International Institute of Tropical Agriculture, IITA), carry out extensive research on cassava in addition to other tropical crops.  Emphasis is placed on developing high-yielding germplasm for low-input conditions.  Present world cassava yields under small-farm conditions average only 5 to 15 t/ha.  Experimental yields of 55 t in Colombia and 70 t/ha elsewhere have been obtained.  Commercial yields with low input in Colombia have exceeded 40 t/ha.  These figures indicate

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that undoubtedly there are several factors limiting production under farm conditions, one of which is pests.

It has frequently been reported that cassava is generally free of arthropod pests; however, present research at CIAT and other centers reveals that mite and insect damage does limit cassava production; e.g., the recent introduction into Africa and the consequent epidemic of the green mite *Mononychellus tanajoa* has caused serious crop losses.

Cassava pests represent a wide range of arthropods; approximately 200 species have been recorded. Although many are minor pests, causing little or no economic losses, several must be classified as major pests. These include mites, thrips, stemborers, hornworms, whiteflies and scale insects.

What little information is available on this subject-scattered in numerous journals and monographs-has been collected and made available to researchers through CIAT's Cassava Information Center. There is paucity of data on cassava pest biology, ecology, distribution, seasonal occurrence and economic damage, often resulting in confusion as to identification, taxonomic classification, determination of synonyms and effective control measures. An attempt has been made to gather information on these pests with recent observations by the authors, whose experience has been mainly in Latin America.

THE HOST PLANT

*Manihot esculenta*, a member of the Euphorbiaceae, is a perennial shrub that originated in the Americas; it was later taken to Africa and more recently introduced into Asia. Common names include mandioca, yuca, manioc and tapioca. Because of the different levels of cyanogenic glycosides it contains in the roots, it has often been classified into "sweet" and "bitter" varieties.

Leaves are formed at active apices and consist of an elongated petiole and a palmate leaf blade. The plant exhibits apical dominate, producing a single stem; the petioles are borne on raised structures, giving the stem a characteristic nobby appearance. When the main apex becomes reproductive, apical dominance is broken; and two, three, or four axillary buds immediately below the reproductive structure become active and branching occurs. The roots accumulate carbohydrates in the parenchyma to form swollen storage organs. Depending on ecological conditions, the plant is cultivated from 8 to 24 months. Although the plant can be grown from seed, it is usually reproduced vegetatively for commercial purposes by planting stem cuttings. Cassava is grown commercially at altitudes between sea level and 2000 meters.

## DISTRIBUTION OF PESTS

The greatest diversity of insects reported attacking is from the Americas. Representatives of the 17 general groups of pests described in this review are found in the Americas, 12 are reported from Africa, and only 5 are from Asia. Undoubtedly, pest distribution is more widely dispersed than the literature indicates.

Mites, whiteflies, white grubs, scales and termites are reported from all major cassava-growing areas. The green mite *Mononychellus tanajoa* is reported only from the Americas and certain parts of Africa, whereas the two-spotted spider mite *Tetranychus urticae* (*T. telarius*) is reported worldwide. The white scale *Aonidomytilus albus* is reported from Asia, Africa and the Americas wereas several other scale species are more localized. White grubs are reported damaging cassava in several regions, but no single species appears universal. The cassava hornworm (*Erinnyis ello*), shoot flies, fruit flies, lace bugs (*Vatiga manihotae*) and gall midges are reported only from the Americas. Stemborers, thrips, mealybugs and leaf-cutter ants are reported from the Americas and Africa. Grasshoppers are reported as a major pest only in Africa. Cutworms and crickets are found worldwide but have not been reported as attacking cassava in all areas.

It appears that the pest complex varies greatly over the the main cassava-growing areas; therefore, careful quarantine measures should be employed to precent their introduction into uninfested areas.

## CROP LOSSES DUE TO INSECTS AND MITES

Insects can cause damage to cassava by reducing photosynthetic area, which results in yield reductions; by attacking stems, which are weakens the plant and inhibits nutrient transport; and by attacking planting material, which reduces germination. Those mites and insects that attack the stem also lessen the quantity and quality of planting material taken from these plants, thus affecting production. Soil-borne insects attack cutting, causing wounds of boring holes through which soil-borne pathogens can enter; they may also completely destroy the epidermis and/or buds of the cuttings. Other cut the roots and /or shoots shortly after emergence. Some insects are vectors of diseases as well.

Indications are that pests such as mites, thrips, whiteflies, scales, mealybugs, lace bugs and stemborers, which attack the plant over a prolonged period, will reduce yield more

than those that defoliate or damage plant parts for a brief period; e.g., hornworms, fruit flies, shoot flies and leaf-cutter ants. This is because the cassava plant appears able to recover from the latter type of damage under favourable environmental conditions, with rainfall and soil fertility being critical factors. Cassava is often grown in regions with prolonged dry season and infertile soils. These additional factors of water stress and poor fertility will compound damage caused by mites, thrips, lace bugs and scales, whose populations tend to increase during dry periods.

Most of the literature reviewed did not include good economic loss data. When quantitative figures were available, they are presented in the text for each insect group.

## MITES AND INSECTS ATTACKING FOLIAGE

### Mites

Recent research indicates that mites are one of the most serious cassava pests throughout the world. A complex of 22 species of spider mites, all belonging to the family Tetranychidae, have been identified as feeding on cassava. The criteria used for identifying these mites and their taconomic description have been reviewed by Flechtman. the more important species of the genera *Tetranychus*, *Mononychellus* and *Oligonychus* are shown in Table 1.

The two species of greatest economic consequence to be *M. tanajoa* and *T. urticae* (*T. telarius*). *T. urticae* is found throughout cassava-growing regions of the world and is reported to cause serious losses in parts of Asia whereas *M. tanajoa* is native to the Americas. It was possibly introduced into Africa around 1970, but may have been presented earlier and has spread quickly because of favorable environmental conditions. *T. urticae* has a wide host range, whereas both the *M. tanajoa* and *Oligonychus peruvianus* mites appear limited to *Manihot* spp. but may attack other Euphorbiaceae. *O. peruvianus* has been identified only in the Americas, but *O. gossypii* has been found in Africa as well.

Yield losses as a result of mites are considerable. Nyira reports yield losses as high as 46 percent caused by *M. tanajoa* in experimental plots in Uganda. Studies in Venezuela (E. Doreste, personal communication) place losses from *M. tanajoa* in the 15 to 20% range. Field experiments at CIAT incolving a complex of four mite species (*M. tanajoa, M. McGregori, T. urticae* and *O. peruvianus*) resulted in 20 to 53% loss, depending upon plant age and the duration of the attack.

346

Damage

The *Mononychellus* mite is usually found the growin points
of plants, on buds, young leaves and stem; the lower part is
less affected.  Upon emerging, leaves are marked with yellow
spots, lose their normal green color, develop a mottled, bronz-
ed, mosaiclike appearance and become deformed.  Under severe
attack, plant growth is stunted, shoots lose their green color
and stems become scarified, first turning rough and brown and
eventually presenting dieback.  Stems and leaves necrose pro-
gressively from top to bottom.

Damage from the *Tetranychus* mite appears initially on the
lower leaves of the plant.  It first shows as yellow dots along
the main leaf vein, eventually spreading over the whole leaf,
which turns reddish, brown or rusty in color.  Beginning with
the basal leaves, severely infested leaves dry and drop, and
plants may die.

The presence of the *Olygonychus* mite is characterised by
small white spots, which are webs the female spreads on the
leaf undersides, commonly along the central and lateral leaf
veins and margin.  Eggs are deposited under this wev where the
immature stages develop.  Corresponding yellow-to-brown dots
form on the leaf upper surface.  Damage is more pronounced on
the lower leaves.


Life History, Appearance and Habits

Mites are pests primarily during the dry season when favor-
able environmental conditions permit populations to buidl up to
high levels.  At CIAT mite populations increased during the dry
season and as the plant increased in age.

The *Mononychellus* female oviposits on the leaf undersurface,
along the midrib or other veins, or in leaf concavities.  As the
mite population increases, eggs are deposited at random.  Nyiira
states that mite density and egg production are enhanced by dry
periods, new leaf growth and high quantities of chlorophyl; they
decrease during and after rains.  Preoviposition lasts 1-3 days,
with females laying from 15-111 eggs each.  Laboratory condi-
tions produce the following time periods for the various stages:
egg, 3-5 days; larvae, 1-2 days; protonymph, 1-2 days; deutonymph,
1-2 days; and adults up to 30 days.  Laboratory studies at CIAT
revealed a sex ratio of 62% females and 38% males and an egg
viability of 92%.  The adult *M. tanajoa* is green color and has
an average body length of 350 mµ.  *M. McGregori* is similar in
behavior to *M. tanajoa*.  We have often observed *M. tanajoa* feed-
ing on leaves still within the bud, whereas *M. McGregori* feeds
on the young leaves after they have expanded from the bud.  Both
species have been found on the same plant in Venezuela (E. Do-

reste, personal communication) and Colombia. Laboratory stu-
dies indicate that optimal temperature for *M. tanajoa* develop-
ment is 28-32°C with a relative humidity of 60%.

Studies by Byiira and Bennett & Yaseen show that wind is
the primary means of dispersal for *M. tanajoa*. These mites
form ballooning threads by which they lower themselves from the
leaves. They are picked up and carried by air currents for
long distances; thus movement of the mite is usually in the di-
rection of the wind. Dispersal is most active on hot days (25
°C), between the hours of 9-11 am and 3-5 pm. Dispersal via
man, animals or other insects, as well as by walking, is also
important. This mite was probably introduced into Africa via
cuttings.

The two-spotted spider mite (*T. urticae*) is considered a
major agricultural pest worldwide and has been studied by se-
veral workers (often as *T. telarius*); however, there are few
studies in relation to its association with cassava. Laborato-
ry and screenhouse studies at CIAT indicate that cassava is an
acceptable host for this mite.

Oviposition is initiated on day 2 of the adult stage, on
the undersides of basal leaves. Each female is capable of ovi-
positing 40-50 eggs over a 20-day period, with the peak period
occurring from days 3-9. Laboratory studies (25-28°C, 60-70%
RH) resulted in an egg period of 3-4 days, a larval period of
2-5 days, a protonymph period of 1-2 days, a deutonymph period
of 1-3 days and an egg-to-adult period of 7-11 days; adults sur-
vived up to 22 days. Dispersal occurs via wind (although not
by ballooning threads), walking or phoresy.

Studies of *Olygonychus* mite on cassava are incomplete. The
female spreads a small whitish web along the central and lateral
veins on the undersides of basal leaves. Eggs are oviposited
under this web, where larvae and nymphs develop by feeding on
the leaf.

Control

The use of pesticides to control mites should be avoided.
Their short life cycle enhances the development of resistance
to acaricides, and predators are more adversely affected by
broadspectrum pesticides than mites are. There is also some
evidence that the application of pesticides can stimulate the
fecundity and migration of mites. To prevent mite infestation
on cuttings, pesticides such as malathion and Tamaron should be
used. These products can be applied by dipping the cuttings in
a solution for five minutes. The two primary methods of control
under study are biological control and host plant resistance.

## Biological control

Numerous predators have been reported feeding on cassava mites. These include Coccinellidae (*Stethorus* sp, *Chilomenes* sp, *Verania* sp) Staphylinidae (*Oligota minuta*) Cecidonyiidae, Thysanoptera, Phytoseiidae (*Typhlodromus limonicus, T. rapax*) and Anthocoridae (*Orius insiduous*). *O. minuta, Stethorus* sp. and the Phytoseiidae mite comples appear to be the more common predators of *M. tanajoa.*

Bennett and Yaseen have evaluated the effectiveness of bio- logical control of *M. tanajoa* with *O. minuta*. The development period of *O. minuta* is only 15-18 dyas, enabling it to react quickly to an increase in host number. Both larvae and adults feed voraciously on the mite (as many as 88 larvae and 32 adults per 75 leaf samples have been observed) and can feed on other tetranychids when *M. tanajoa* is scarce. Predator populations were greater during the dry season when mite density was high- est and decreased during the rainy periodm as did mite density. *O. minuta* populations; its activity is therefore synchronized with that of the mite. The introduction of this predator into east Africa has begun.

## Varietal resistance

Systematic evaluation of the CIAT germplasm bank under greenhouse and screenhouse conditions indicates only low levels of reistance to *T. urticae* and intermediate or moderate levels to *M. tanajoa*. Nearly 98% of the varieties were high suscepti- ble to *T. urticae*, as compared to 45% for *M. tanajoa*. Only 0.4 % of the varieties were in the intermediate resistance range for *T. urticae*, as compared with 14% for *M. tanajoa*. These results indicate that there is a higher level of resistance to *M. tana- joa* than to *T. urticae* in cassava germplasm.

Bennet & Yaseen observed large differences in population levels of *M. tanajoa* on different varieties. Nyiira found the lowest *M. tanajoa* population on the varieties Kru 46, 301, 15 and K.Kawanda. During heavy attacks, he observed three times as many leaves on tolerant varieties as on susceptible ones, and leaves developed about four times more slowly on susceptible varieties. Root yield of resistant varieties was about twice that of susceptible ones. Reports from Brazil and Venezuela have also identified varieties resistant to *Mononychellus* and *Tetranychus*. In recent field evaluations in Colombia, several varieties were selected as promising for resistance.

## Thrips

Several species of thrips are pests of cassava throughout the Americas. These include *Frankliniella williamsi*, *Frankliniella* sp., *Corynothrips stenopterus*, *Euthrips manihoti*, *Scirtothrips manihoti* and *Caliothrips masculinus*. Thrips attacks have also been reported from Africa (Z.M. Nyiira, personal communication) and India (*Retithrips syriacus*, Bellotti, personal observation). Yield reduction ranges from 5.6-28.4% depending on varietal susceptibility. The average reduction for eight susceptible varieties in Colombia was 17.2%. These results are consistent with reports in literature, which estimate a 15% yield reduction.

## Damage

*F. williamsi*, which damages the terminal bud of the plant, is the species of greatest economic importance. Leaves do not develop normally, leaflets are deformed and show irregular chlorotic spots. Stylet damage to leaf cells during expansion causes deformation and distortion and parts of the leaf are shortened. Growin points may die, causing growth of lateral buds which, in turn, may be attacked, giving the plant a witches'-broom appearance. Symptoms of a severe attack are similar to those for cassava mosaic.

## Life History, Appearance and Habits

Limited information is available on the biology of thrips on cassava. Larvae and adults of *E. manihoti* and *F. williamsi* in the growing points and on young leaves. *Frankliniella* sp. and *F. manihoti* are golden yellow and measure about 1.1 mm in length. *C. masculinus* a black species, is found mainly on expanded leaves of young plants. Adult *C. stenopterus* measure 1.5 mm and are yellow in color; the head and the las two abdominal segments are darkened. Thrips insert their eggs in the midrib of the leaf undersurface. The greenish colored nymphs live near the veins where they go to through two nympha¹ and two pupal stages. Thrips attack is most frequent during dry periods, and plants recover with the initiation of the rainy season.

## Control

The use of resistant varieties, which are readily available is the best method of control. In the CIAT germplasm bank high levels of resistance to *Frankliniella* sp. and *C. stenopterus* exist. Approximately 20 percen of the varieties are highly

resistant to thrips attack, and an additional 29 percent show
only minor damage symptoms. Resistance is based on leaf bud
pilosity. Increasing pubescence of unexpanded leaves increas-
ed thrips resistance.


The Cassava Hornworm

The cassava hornworm *Erinnyis ello* it generally considered
to be one of the most serious pests because it can rapidly defo-
liate plants. It occurs only in the Americas, where in severe
outbreaks large cassava plantations are defoliated. This pest
has been reviewed in detail by Winder. The hornworm has been
previously recorded as *Sphinx ello*, *Dilophonota ello* and *Ance-
ryx ello*. A less important species *Erinnyis alope* has been re-
ported in Brazil. Cassava is the principal host of *E. ello*,
which appears to be confined to Euphorbiaceae. Additional hosts
reported are *Aleuritis triloba*, *Manihot glaziovii*, poinsettia,
rubber, papaya and milk weed. When heavy attacks occur, larvae
may migrate to adjacent crops such as cotton. Yield reductions
of 10-50% Have been estimated depending upon plant age and in-
tensity of attack; at CIAT yield was reduced by 18%. A decrease
in starch content has also been suggested. Transmission of bac-
terial blight by hornworm larvae has also been reported.


Damage

Hornworm outbreaks with populations of more than 90 larvae
per plant have been reported. Populations of this magnitude
will defoliate plants rapidly, and the larvae will subsequently
feed on growing tips and lateral buds. Young plants may be kil-
led. The influence of hornworm attack on the roots is severe
in poor than in fertile soils. Damages simulation studes indi-
cate that defoliation of young plants (2-5 months) reduces
yields more than that of older plants (6-10 months). Although
each larva consumes an average of 1107 $cm^2$ of leaf area during
its five instars, large population can be tolerated since under
favorable environmental conditions there can be up to 80% defo-
liation with no reduction in root yield.


Life History, Appearance and Habits

The generally gray nocturnal adult moth has five to six
black bands accross the abdomen, with gray forewings and reddish
hind wings. The smaller males have a longitudinal dark band
over the forewings. Females live 5-7 days, and the males live
a few days less. Oviposition occurs 2-3 days after emergence,
usually on the upper surface but also on the petiole, stems and
leaf underfaces. A female may deposit from 30-50 eggs although

recent observations at CIAT (unpublished data) indicate an average of 850 eggs for individual pais and 450 when there were 11 pais in the cage. The eggs hatch in 3-6 days.

The first instar larvae consume the egg shell before moving to the leaf undersurface to begin feeding. The duration of the five larval instars is from 12-15 days. Larvae prefer feeding on upper leaves, consuming approximately 75% of the total leaf area in the fifth instar. The hydrogen cyanide content of the leaf appears to have no effect on larval mortality but leaf age does. All instars show color polymorphism, but htis is more common during the third instar. Colors vary from yellow, green, black, red and dark gray to tan.

Fifth instar larvae may reach 10-12 cm in length; they migrate to the soil where they form chesnut brown, black-lined pupae under plant debris. Larvae may crawl considerable distances prior to pupation. Pupae can diapause for several months, but the adults normally emerge within 2-4 weeks. Hornworm outbreaks generally occur at the onset of either rainy or dry periods, but attacks are sporadic and the insect can be virtually absent for several years. In Brazil they are found all year but are most abundant from January to March; several generations may occur. In Colombia outbreaks occur mainly during the dry periods.

Control

A biological control program that combines parasitism of eggs and larvae, as well as predation, appears to be the most effective. Severe outbreaks can be reduced by applying *Bacilus thuringiensis*. Chemical control should be avoided as infestation is less frequent in nonchemically treated than in treated fields.

Egg parasitism by *Trichogramma minutum*, *T. fasciatum*, *Trichogramma* spp. and *Telenomus dilophonotae* has been reported to be as high as 94-99%. An average of 23 *Trichogramma* adults emerge per egg. Experiments at CIAT were designed to measure the effect of *Trichogramma* release on hornworm egg parasitism. Egg parasitism was measured prior to release and periodically postrelease. Tesults showed a 22-23% increase in parasitism four days after release. *Trichogramma* are being released in large cassava plantations in Colombia. Egg predation by ants (*Colichorerus* sp.) and wasps (*Polibias* sp.) has also been reported.

Of the reported insect and vertebrate predators of larvae, the paper wasps (*Polistes canadiensis* and *P. erytrocephalus*) appear to be the most effective. Each wasp requires several larvae per day, for its own consumption as well as for its brood.

Control is most effective when tentlike protective shelters are provided for the wasp in the center of the cassava field. This practice has been successufl at CIAT and on same farms in Colombia. Other larval predators are a pentatomid, *Alceorrhynchus grandis*, and a carabid, *Calosoma retusum*, Predation by birds is also important in several areas of Brazil and Colombia.

Important larval parasites in Colombia are *Apanteles congregatus* and *A. americanus*. These braconid parasites oviposit in the hornworm larvae where the parasite larvae develop. Mature larvae migrate from the host and pupate on the outer skin, forming a white, cottonlike mass. These cocoons are approximately 3.8 cm wide by 4.1 cm long. Each cocoon contains an average of 257 *Apanteles* pupae, of which some 80% will emerge. Liberations at CIAT resulted in an increase in parasitism of hornworm larvae. Hyperparasitism of *Apanteles* by several hymenopteran parasites was recorded at CIAT, resulting in an average of 56% hyperparasitism. Similar behavior is reported for the ichneumonid wasp *Microgaster flaviventris*. Larval parasitism by tachinid flies is also reported. *B. thuringiensis* controlled hornworm larvae effectively at CIAT. Six days after application, the larval population was 8% of the control; i.e., one per plant versus 13 on the control. Additional experiments show that *B. thuringiensis* is effective against all larval instars but most effective against the first. Studies also show that application of *B. thuringiensis* does not have an adverse effect on *Trichogramma* egg parasitism.

Laboratory studies at CIAT were designed to determine length of larval survival after initiating feeding of *Bacillus*-treated foliage. Results showed that larvae can survive for 1 to 4 days. however, the leaf tissue they are able to consume is reduced by 86% for the third instar, 93% for the fourth instar and 98% for the fifth instar larvae.

Cultural control practices such as plowing between rows and after harvest, as well as mechanical weed control, will destroy mature larvae and pupae. Hand-picking of larvae is recommended for farmers with small plantings.

### Whiteflies

Whiteflies (Aleyrodidae) attack cassava in the Americas, Africa and certain parts of Asia. Although they may not cause economic damage by their feeding, they are of particular importance as vectors of African and India. *Bemisia tabaci* is the most important species in these areas. *B. gossypiperda* and *B. nigeriensis* are also reported from Africa. The species most frequently found in cassava in the Americas are *Trialeurodes variabilis*, *Aleurotrachelus* sp., *B. tuberculata* and *Aleurothrixus* sp. Although *B.tabaci* has been reported from the Americas,

there is some doubt as to its capacity to feed on cassava. African mosaic disease, reviewed by Lozano & Booth, is not present in the Americas.

Damage

High whitefly populations may cause yellowing and necrosis of the lower leaves of the cassava plant. Severe infestations of *Aleurotrachelus* sp. have been observed in Colombia, where leaf damage was manifested as severe mottling or curling, with mosaiclike symptoms on susceptible varieties. A sooty mold, often found growing on whitefly excretions may have an adverse effect on plant photosynthesis. Yield losses as high as 76% have been recorded at CIAT (unpublished data).

Life History, Appearance and Habits

The biology of *Bemisia* spp. has been reviewed by Leuschner. The cycle varieties with temperature; at 26°C, 17 days are required from egg to adult; within a range of mean temperatures from 12-26°, the cycle varies from 11-50 days. During hot, dry weather and low relative humidity, no eggs are laid. One generation of *B. tabaci* lasts 4-5 weeks, depending on climatic conditions; there may be up to ten generations per year.

Studies on the biology of *T. variabilis* showed that females deposit an average of 161 eggs with 72% survival from egg to adult. Average longetivity for females was 19.2 days; for males, 8.8 days. The oblong pupal stage is normally pale green, but that of *Aleurotrachelus* sp, is black, with a white waxy excretion around the outer edge. Heavily infested leaves are almost covered with immature stages, which gives the undersurface a glistening white effect. Infestations have been observed on upper as well as lower leaves.

Adult whiteflies are almost always found on the undersides of developing leaves, wehre they oviposit. Activity depends on temperature, light and rainfall; temperature and light seem to have an interacting effect on flight activity. Temperatures of 27-28°C increase activity but do not induce flight; as light becomes more intense, flight increases.

High populations are usually associated with the rainy season when plants are more vigorous. Detailed population studies of *Bemisia* sp. have been conducted at IITA; possible factors involved in fluctuations of population may be a combination of ecological factors, physiological conditions of the plant, parasites and predators.

## Virus/Vector Relationship

Experiments conducted at IITA have shown that vector density and African mosaic incidence are related. In screenhouse studies on the virus/vector relationship. Chant demonstrated that whiteflies have to feed for at least 14 hours acquire the "virus" and another 4 hours to become viruliferous; they are then able to transmit the disease after a minimum feeding period of 15 minutes. There are no results available for vector efficiency under field conditions; however, it is probably dependent on flight activity of the adults, population density and availability of young (succulent) infected leaves.

## Control

One way of controlling the vector is by using insecticides, but repeated treatments are necessary to maintain low populations, making this practice uneconomical. In addition numerous wild hosts for *Bemisia* spp. would have to taken into consideration as new populations can build up quickly from these sources. Transmission pressure can be reduced by using resistant varieties. Studies at CIAT indicate that resistance to *Aleurotrachelus* sp. is available.

Biological control may be feasible. The coccinellid *Serangium cinctum* preys on immatures; the mite *Typholodromite* sp. feed on adults. The wasp *Prospaltella* sp. (Encyrtidae) has been reported to parasitize whiteflies.

## Leaf-cutter Ants

Several species of leaf-cutter ants, all belonging to the genera *Atta* and *Acromyrmex*, have been reported feeding on cassava in the Americas, especially Brazil and Guyana. The most commonly reported are *Atta cephalotes*, *A sendex*, *A. leavigata*, *A insulans* and *A. opaciceps*; *Acromyrmex rugosus*, *A. octospinosus* and *A. diselager*.

## Damage

Cassava plants can be defoliated when large number of worker ants move into a crop. A semicircular cut is made in the leaf; during severe attacks, the buds may also be removed. These parts are carried off to the underground nest and chewed into a paste, on which the fungus *Rhozites gongylophora* is grown. Outbreaks frequently occur during the early months of the crop; the effect on yield is not known.

## Control

Insecticides are the most effective means of control.
Nests, often readily visible by the sand piles around the en-
trance hole can be destroyed by fumigation with carbon disulfi-
de and sulfur smoke or arsenates.  Chlorinated hydrocarbons
round the nest or granular Mirex baits applied along the ant
trails give effective control.  Varietal differences to ant
attack are mentione.  Cacao, a host preferred to cassava by
some of the ant species, has been planted with cassava as a
protective measure.

## Grasshoppers

Numerous  species of grasshopers are reported attacking
cassava, principally in Africa.  It is reported that resistance
of cassava to the migratory locust has stimulated cassava pro-
duction in many areas of Africa.  Grasshoppers have been observ-
ed feeding on cassava in the Americas but are not considered
to be a major pest there.  The two species of major economic
significance are *Zonocerus elegans and Z. variegatus*, both wide-
spread in Africa between 10° north and south of the equator.
Yield losses as high as 60% have been reported when younger
plants are attacked.  They may also be disseminators of cassava
bacterial blight (J.C. Lozano, personal communication).

### Damage

Feeding damage is usually restricted to defoliation but
can include young tender bark and seed coasts; in heavy out-
breaks the bark is stripped.  Immature plarts are more severely
affected than mature ones, which can withstand defoliation and
have successful regrowth.  Damage is of major importance during
the dry season when cassava, which is tolerant to drought, is
often the only available food source.  It has been reported
from some areas that the roots of defoliated plants are inedible
because of excessive hardness.

### Life History, Appearance and Habits

The biology of *Z. variegatus* in Nigeria has been studied
by Jerath and Toye.  Adults generally lay eggs in April, placing
them in eggpods a few centimeters below the soil surface; hatch-
ing occurs about 8 months later.  The five nymphal stages last
about  2 months.  *Z. variegatus* is a mass migrator whereas *Z.*
*elegans* migrates individually.  Migration and feeding habits of
Z variegatus have been studied in Nigeria and Ghana.  Increased
cassava cultivation appears to intensify problems with *Zonocerus*.

Bernays *et al* studied the survival of *Z. variegatus* on cassava and showed that young nymphs normally reject cassava after biting it and die if they are confined on growing leaves. Later instars, if deprived of alternate food sources, will eat cassava, but adults progressively lose weight. Readiness to feed on growing cassava was associated with low HCN levels in the leaves.

## Control

Definite varietal preference have been noted in studies of feeding habits of *Z. variegatus*, possibly related to acceptability of the bark of certain varieties. On the other hand, the HCN content of varieties has been linked with resistance; however, its role has not been sufficiently confirmed.

With regard to cultural control, planting should be done at a time that would ensure plant maturity when peak grasshopper populations occur since they prefer young, developing plants. The use of chlorinated hydrocarbons has also been recommended.

Biological control may also be feasible as *Z. variegatus* is parasitized by mermithid worms and the dipteran *Blaesoxipha filipjevi*.

## Gall midges

Gall midges (Cecidomyiidae) have been reported on cassava only in the Americas. The species *Jatrophobia brasiliensis* (= *Eudiplosis brasiliensis. Clinodiplosis brasiliensis*) appears to be the most widespread.

## Damage

Gall midges are considered of little economic importance and generally do not require control. However, in Peru and Mexico, 6- to 7-month-old plants were totally deformed, measuring only 20-30 cm high as a result of a severe attack. Under high population leaves yellow, retarding plant growth; roots become thin and fibrous.

## Life History, Appearance and Habits

Adults lay from 4 to 5 individual eggs per leaf. When the larvae emerge, they penetrate the parenchyma tissue, causing abnormal cell growth and the formation of a gall (one larvae per gall) during the first larval instar. The second and third

instars are passed here. Leaf galls generally measure 5-15 x 3-5 mm and are found on the upper leaf surface; they are yellowish green to red, narrower at the base, often curved and easily noticeable. Larval duration is 15-21 days. Pupation (10-15 days) occurs in the gall; prior to pupation, the larva enlarges the exit hole, which is surrounded by a ring of elevated tissue, through which the adult emerges.

Control

Varietal resistance to gall midges has been reported. The collection and destruction of affected leaves at regular intervals has been recommended to reduce pest populations.

Several larval parasites of gall midges have been observed, including *Tetrastichus* sp. *T. fasciatus*, *Dimeromicrus auriceps*, *Aprostocetus* sp. and *A. fidius*.

Cassava Lace Bug

Lace bug (*Vatiga manihotae*) damage is reported from Colombia, Brazil and several other countries in the Americas. The species          has been reported from Brazil. High populations can cause foliar damage. Leaves have yellow spots that eventually turn reddish brown, resembling mite damage. Yield losses are not known, but observations in Brazil indicate severe defoliation in certain areas, possibly causing yield reductions.

Life History, Appearance and Habits

The grayish adults, about 3 mm long, are generally found on the undersurface of the upper leaves. The whitish nymphs are smaller and are usually found feeding on the central part of the plant. Laboratory studies at CIAT show five nymphal stages lasting 2.9, 2.6, 2.9, 3.3, and 4.8 days, respectively (totaling 16.5 days). The egg stage is about 8 days; females deposit an average of 61 eggs. Adult longevity averages about 50 days. Prolonged dry periods were favorable for increased lace bug population, which were highest during the first 3 months of plant growth.

INSECTS ATTACKING STEMS

Stemborers

Numerous insect species have been reported to feed on and damage stems and branches of cassava (Table 2). Although near-

ly worldwide in distribution, they are of particular importance
in the Americas, especially in Brazil. They generally cause spo-
radic or localized damage, and none can be classigied as univer-
sal pests.

The most stemborers belong to the orders Coleoptera and Le-
pidoptera. The dipterans *Anastrepha* spp. (fruitflies) and
spp. (shoot flies) which may also bore into the stem, are des-
cribed separately in this report. Stemborers appear to be high-
ly host specific and few are reported to feed on alternate hosts.
Two species, *Megasoma elephas* and *Syllepta gordialis*, are report-
ed to feed on swollen roots in Venezuela. Several lepidopteran
and coleopteran stemborers are identified from Africa; the only
one reported from Asia is *Lagochirus* sp. from Indonesia. Seven
species of *Coelosternus* are reported attacking cassava in the
Americas, and *C. manihoti* is reported as a pest in Africa.
Only *Coelosternus* spp. and *Lagochirus* spp. are discussed in de-
tail here.

*Coelosternus* spp.

Damage.- Larvae of the *Coelosternus* weevils cause damage
by penetratin the stem and tunneling into the center or pith
region, which weakens the plant; stems and branches may eventual-
ly dry and break reducing the quantity and quality of planting
material. Although larvae of *C. sulcolutus* have been observed
feeding on underground parts of the stem, they have never been
found attacking roots, but they can reduce root production.
Frass and exudate from the stem wood, ejected from burrows by
feeding larvae, can be found on infested branches or on the
ground below the plants. Adults also feed on the tips of young
shoots or stems, which may retard growth.

Life History, Appearance and Habits. Females may oviposit
on various parts of the plant but prefer the tender parts. In
*C.alternans*, oviposition has been observed near broken or cut
ends of branches or beneath the bark in cavities made by the
proboscis. Oviposition by *C. granicollis* begins 3 days after
copulation; the female penetrates the stem, depositing up to
several white eggs, often no more than one per day.

Larvae vary in size depending upon the species. Fully
grown larvae of *C. alternans* are 16 mm in length with a maximum
width of 4 mm, whereas those of *C. tarpides* are 9x2.5 mm. Most
larvae are curved, with a yellowish white to pale brown body, a
reddish brown head capsule and black mandibles. In *C. rugicollis*
only a single larva is found in each stem, whereas in the other
species there may be several. the larval period ranges from 30-
60 days. The fully grown larvae of all species pupate within a

cell constructed in the pith region. The pupa is held securely in place in its chamber at one end of the burrow with larval frass; duration of the pupal period is about 1 month. After emerging from the pupal case, the adult may remain in the chamber for several days before leaving the stem. Adults range in size from 6 mm in length for *C. granicollis* to 12 mm for *C. alternans* and *C. rugicollis*. Adults are light to dark brown and may be almost completely covered with yellowish scales. They are active throughout the year, but activity may decrease during cooler months in some areas.

*Lagochirus* spp.

Larvae of *Lagochirus* spp., long-horned beetles, cause damage similar to that of *Coelosternus*.

<u>Life History, Appearance and Habits.</u>- Adults oviposit in stems and branches about 2.5 cm below the bark; eggs hatch in 5-6 days. The larvae, which take about 2 months to develop, measure up to 29 mm; they feed at the base of the plant and many can be found in one plant. The pupal period, which lasts about 1 month, takes place in the larval chambers in the stem. Adults are nocturnal, rapid fliers, active throughout the year. They are brown in color, about 17 mm long and feed on leaves and bark.

Control

Since adult stemborers are difficult to kill and larvae feed within the stems, pesticidal control is impractical. Resistance to *Coelosternus* spp. has been found in the lines 103 Brava de Itu and 192 Itu. Cultural practices that will reduce pest populations include removal and burning of infected plant parts. Only uninfested and undamaged cuttings should be used for propagation.

Fruit Flies

Two species of fruit flies, *Anastrepha pickeli* and *A. manihoti* (Tephritidae) have been identified attacking cassava in Colombia. The fruit fly was originally reported attacking the fruit, where it causes no economic losses. We have observed fruit flies causing severe damage to stems in Colombia, Venezuela and Central America.

## Damage

When oviposition occurs in the fruit, the larvae bore throughout the fruit, destroying the developing seed. The infested fruit will shrivel and become soft, turning yellow green in color. Larval tunneling in the stem results in brown galleries in the pith area.

A bacterial pathogen (*Erwinia carotovora* var. *carotovora*), often found in association with fruit fly larvae, can cause severe rotting of stem tissue. A white exudate may flow from the larval tunnel and exit holes. As a result of severe attacks, growing points may collapse and die, retarding plant growth and encouraging growth of lateral buds. This secondary rotting may cause a reduction of yield and a loss of planting material. Damaged stems have a rotted pith area and germination of cuttings from this material can be reduced by as much as 16% and may be delayed by several weeks. In experiments at CIAT, as many as 84% of the plants have been attacked.

Root losses are suspected but not known. It appears that plant age at the time of attack is important; younger plants (2-5 months) suffer more damage. Cassava plants can apparently recover rapidly from fruit fly damage, given adequate, well-distributed rainfall. Plants that had severe rot ar 3 months with dead or rotted growing terminals, were compared to healthy plants over a 6-month period. Plant height measurements showed that within 5 months the damaged plants had recovered and attained the same height as the nondamaged ones.

Investigations were carried out at CIAT to determine germination and yield losses due to the use of *Anastrepha*-damaged planting material. Cuttings were separated into five groups, based on damage grades ranging from 0 (no damage) to 4 (severe rotting and tunneling throughour the pith area). Results showed a decrease in cutting germination, ranging from 5% for grade 1 to 16% for grade 4, an average of 9% reduction in germination for damaged cuttings. In addition, plants from damaged cuttings yielded 17.4% less than those from undamaged cuttings; this means a loss of nearly 7 t roots/ha.

## Life History, Appearance and Habits

The yellow- to tan-colored female inserts the egg in the succulent part of the stem, about 10-20 cm from the tip, so that about one third of the egg with a slender white rod protudes. After hatching, the white to yellow larvae bore up- or downward in the stem pith regions. Since numerous eggs may be deposited in one stem, several larvae may be found per stem.

The fruit fly/bacterium association is not fully inder-
stood. It appears that the bacterium is present on the stem,
where it can live epiphytically. Although it is probably not
transported by the fly, the boring action of the larvae under
high humidity conditions provides the wound needed for bacte-
rial entrance into the stem. Under favorable environmental
conditions of adequate rainfall and high humidity, rotting de-
velops. Rotting does not seem to favor larvae; inspection of
rotting stems showed 40% larval mortality. Thus major fruit
fly population increases may result from infestations of the
cassava fruit or alternate hosts rather than from stem infesta-
tions.

Mature larvae leave the stem or fruit and pupate on the
ground. The larval exit hole is clearly visible in the stem.
Adults emerge in about 17 days. High fruit fly populations oc-
cur year round, but extensive damage is usually associated with
the rainy season.


Control

Since several damage coincides with the rainy season, ra-
pid plant recovery is facilitated and control measures may not
be required. An evaluation of CIAT's germplasm bank indicated
varietal differences in degree of larval attack. Larval parasi-
tism, as high as 16%, by a braconid *Opius* sp. has also been ob-
served in the fruit; however, parasitism of larvae in the stem
has not been found. Hydrolyzed maize was the most successful
attractant used in traps for adults. As regards chemical con-
trol, it was found that fenthion, applied as a foliar systemic,
gave nearly 100% control of the larvae in the stem.


Shoot Flies

Shoot fly damage has been observed in most of the cassava-
growing regions of the Americas. This pest has not been report-
ed from Africa or Asia. Several species, all belonging to Lon-
chaeidae, have been described, but *Silva pendula* *Lonchaea
chalybea* are the most important *S. pendula* [= *Carpolonchaea pen-
dula*. *Lonchaea pendula, L. batesi, L. glaberrina*] is known to
attack several other hosts including *Mammea americana, Mangiera
indica, Inga feullei, Eugenia* sp, *Atrus* sp. and *Capsicum frutes-
cens*. Other shoot flies are *Silva perezi, Antherigona excisa,
A. excelsa, Euxesta eluta* and *Neosilba perezi*. Only *S. pendu-
la* will be discussed in detail, the behavior of which is simi-
lar to that of *L. chalybea* and *S. perezi*.

362

Damage

Larval feeding damage is manifested by a white to brown exudate flowing from the growing points which eventually die. This retards that plant growth, breaks apical dominance and causes germination of side buds, which may also be attacked. These symptoms resemble witches'broom disease. In some cases only part of the tip is killedm and the shoot continues to grow.

Young plants are more susceptible to attack may cause plant stunting. During severe outbreaks, 86% of the plant population has been reported affected. At CIAT simulated damage studies, removing 50 and 100% of the shoots on plants 2-5 and 6-9 months of age, showed that the degree of economic damage is dependent upon plant variety and age. The late-branching variety MEcu 150 was more susceptible than Llanera at early stages (2-5 months), and yield was reduced by about 30%. Shoot removal from 6-9 months did not affect yields of either variety. On an individual plant basis, there was a 15.5, 16.7 and 34.12% yield reduction when natural attack occurred at 4.5, 5.5 and 6.5 months, respectively. Affected plants were shroter and may have been shaded by healthy neighbors; hence these yield losses may be overestimated.

Studies in Costa Rica showed that shoot fly attack resulted in increased branching, foliage and production. Simulated damage studies in Florida resulted in reduced height of damaged plants (159 cm vs. 241 cm) and an increased number of terminals for plants attacked once a month. However, there were no significant yield differences. Damaged plants had approximately the same number of leaves as undamaged ones.

Life History, Appearance and Habits

The dark metallic blue adult of *Silba pendula* oviposits between the unexpanded leaves in the growing points or in a small cavity made in the tissue by the ovipositor. As many as 22 eggs per shoot have been observed but 3-8 eggs per shoot is average. The eggs hatch in about 4 days, and the young larvae tunnel in the soft tissue, eventually killing the growing point. Several whitish larvae may be found in the affected tip, It is claimed that the larval exudate gives protection against parasites and insecticides. The larval period is about 23 days; larvae pupate in the soil and the adult fly emerges about 26 days later. The fly is especially active on sunny days.

Development of the immature stages of *N. perezi* appears similar to *S. pendula*, but the adult of *N. perezi* lives 3-5 times longer than that of *S. pendula*.

Attacks may occur throughout the year; but in many areas they are seasonal, often at the onset of the rainy season. At

CIAT the dry period was favorable for higher shoot fly populations.

Control

The lack of data showing significant yield losses due to shoot fly damage indicates that control measures may not be necessary. Insecticide applications should be avoided since they are costly and their effectiveness, in terms of increased yields, has not been proven.

Cultural Practices.- Destruction of infested shoots at weekly intervals has been recommended but is not believed effective since there are alternate hosts. Planting dates can be adjusted so that the younger growing stage is passed during low shoot fly population.

Resistance.- Distinct varietal differences in susceptibility to shoot flies have been observed, but no extensive screening has been done. In Guadeloupe, the varieties Petit Bel Air 4, Rais Blanc, Campestre 10 and Gabela were more resistant to *L. chalybea*. In Brazil, the varieties IAC 1418 and Ouro do Vale showed some resistance to *S. pendula*.

Chemical Control.- Larvae are difficult to control. Systemic organophosphates have been used during early attacks when populations are high. Insecticides and a sugar solution sprayed on plant act as a bait for adult control. Fly traps with insecticide, using decomposing fruits, casein or yeast as attractants, are also effective.

Scale Insects

Several species of scales have been identified attacking stems in many cassava-growing regions of the Americas, Asia, and Africa (Table 3).

The most important scales appear to be *Aonidomytilus albus* and *Saissetia* sp. *A. albus* has been observed on cassava throughout most of the cassava-growing regions of the world. This scale, which may have been disseminated from one continent to another on planting material, is now the most widely distributed cassava pest.

## Damage

Leaves on attacked stems yellow and fall; in severe attacks the plants are stunted, the terminal bud can be killed and stems can dessicate, causing plant mortality. Heavy scale populations may cover the stem and lateral buds. *Saissetia coffeae* is reported attacking leaves, causing leaf curling. Scale damage appears to increase when cassava is planted continually on the same land. Outbreaks are severest during the dry season, thus aggravating drought stress.

The greatest damage from scale attack appears to be the loss of planting material as a result of the death of lateral buds. Studies at CIAT with cuttings heavily infested with *A. albus* resulted in 50-60 % loss in germination. Stored cuttings can also be lost because of scales.

Recent studies at CIAT showed that yield losses due to *A. albus* can reach 19% on a susceptible variety when the stem is almost completely covered with scales, causing severe defoliation and occasionally death of the terminal bud. Reduction in yield and root quality have been reported.

## Life History, Appearance and Habits

The biology of *A. albus* has been studied in detail by Swaine. The female scale of *A. albus* is mussel shaped and covered with a white waxy excretion. The cast skins of the first and second nymphal stages are incorporated in the scale. Unlike the females, males have well-developed legs and wings. The female produces an average of 47 eggs, depositing them between the upper scale covering and the lower cottony secretion. During oviposition the female shrinks and shrivels up. Eggs hatch in 4 days; the first nymphal instars (crawlers) are locomotive and can disperse. These crawler become fixed in 1-4 days, cover themselves with numerous fine threads, molt in 11 days and become immobile. After 4 days the adult female appears and commences oviposition in 1-2 days. One female generation is passed in 22-25 days.

In laboratory studies at CIAT on excised cassava stems, male scales pass through two nymphal stages, averaging 10 and 6.5 days, respectively, and a prepupal and pupal stage of 4.5 days in total. Adults live from 1-3 days and the male life cycle is about 23 days. There are three female nymphal instars, averaging 10, 5 and 9 days, respectively. The third instar is the adult stage. Eggs are oviposited under the scale and nymphs emerge during a 7-day period, with peak emergence occurring from the 3rd to 5th day. Each female produces an average of 43 nymphs.

## TABLE 3. SCALE INSECTS REPORTED ATTACKING CASSAVA

| Family and species | Reported from |
|---|---|
| **DIASPIDIDAE** | |
| *Aonidomytilus albus* | Americas, Africa, Asia |
| = *Coccomytilus dispar* | Asia (Taiwan, India) |
| = *Lepidosaphes dispar* | Africa |
| = *Lepidosaphes alba* | Cuba |
| *Pinnaspis minor* | Peru |
| = *Hemichionaspis minot* | Peru |
| **COCCIDAE** | |
| *Saissetia hemisphaerica* | Madagascar |
| = *Lecanium hemisphaerica* | Mauritius |
| *S. nigra* | Madagascar, Malaysia Indonesia |
| *S. coffeae* | Madagascar |
| *S. miranda* | Colombia |
| *Coccus viridis* | Madagascar |
| *Mytilaspis dispar* | Madagascar |
| *Eurhizococcus* sp. | Brazil |
| *Monophebus* sp. | Brazil |

Females of *Eurhizococcus* sp. are described as very mobile; they enter the soil and in 5-7 days, the ootheca with eggs appears on the soil surface. There are three nymphal instars, totaling 28 days, before the female appears. No males were observed.

Dispersal occurs by wind, active crawling or infested cuttings. The most important means of dissemination is by storing infested cuttings with healthy ones.

Control

The most effective means of control in through the use of uninfested planting material and cutting and burning infested plants to prevent the spread of infestation.

Chemical control.- Chemical control may be required during the drys season. Measured in percentage of adults killed, systemic insecticides and parathion were most effective. As for chemical control of cuttings, dipping those that are infested with crawlers in DDT emulsions for 5 minutes reduces infestation; however, heavily infested cuttings still germinate poorly. The insecticides malathion 4% (1 g/liter), Hostathion (1 cc/liter), Tamaron (1 cc/liter) and Triona + malathion (2 cc + 1 g/liter) all prevented a rapid increase of scale populations after planting.

Biological control.- Heavy predation of *A. albus* by a coccinellid, *Chilocorus distigma* is reported. Hymenopterous parasites, *Aspidiphagus citrinus* and *Signiphora* sp., are reported in Cuba.

We have observed heavy parasitism and predation of *Saissetia miranda* in the field, but the species have not been identified. We have also found a brown, spongelike fungus, *Septobasidium* sp., growing on *A. albus*.

Mealybugs

Mealybug damage to cassava has been reported from Colombia, Brazil, and parts of Africa. The species at CIAT has been identified as *Phenacoccus gossypii*, the Mexican mealybug; and *P. gossypii* and *Phenacoccus* sp. are reported from Brazil. *P. manihoti* has recently been reported from Africa (Zaire) and South America. Other mealybugs reported from Africa are *Pseudococcus virgatus* ( = *Ferrisiana virgata*, *Dastulopius virgatus*), *Pseudococcus citri* and *Pseudococcus adonidum*.

## Damage

There is no record of economic losses in cassava result-
ing from mealybug attack; observations indicate that this pest
is capable of causing crop losses. Albuquerque reported a se-
vere attack of mealybugs causing plant mortality at the Centro
de Pesquisa Agropecuaria do Trópico Umido in Belem, Brazil in
1975. This was the first time this pest was reported from the
Amazon region. All 150 cassava varieties at the center were
susceptible. High mealybug populations cause defoliation and
drying of stem tissue, resulting in a loss of planting material.
leaves will turn yellow and dry, and defoliated plants form
new-buds, which are also attacked.

In Africa, *P. manihoti* first attacks the terminal points
of the shoots, then the petioles and expanded leaves. Inter-
nodes are shortened, there is leaf curling and reduces new-
leaf growth. As population density increases, all green parts
of the damaged shoot eventually die. Infestation of the lower
leaves, together with natural leaf fall during the dry season,
gives the plant a "candlestick" appearance.

## Life History, Appearance and Habits

*P. gossypii* has a wide host range, including food crops
as well as many ornamentals. Females deposit sacks containing
a large number of eggs around the axil of branching stems or
leaves, on the underside of the leaf where the leaf petiole
joins the leaf, or aound the buds on the main stem. The young
nymphs, shortlyafter initiating feeding, exude a white, waxy
material from their bodies, which forms a cover over the in-
sect. High populations give a cottony appearance to the green
or succulent portion of the stem and on the leaf undersurface.
They do not remain fixed but move slowly over the plant surfa-
ce. Adults measure about 2.4 by 1.5 mm.

Life cycle studies of *P. gossypii* were conducted on exci-
sed cassava stems and leaves in the laboratory (temperature
16-28°C, RH 75-85%) at CIAT. There are three female nymphal
instars averaging 8.6, 5.7 and 6.3 days, respectively. Adult
females are able to survive for up to 21 days; oviposition
occurs over a 5-day period, with an average of 328 eggs per
female. Eggs are located in an egg pouch which the female
carries on the posterior end of ther body until the nymphs
hatch. Nymphs are mobile througout their life cycle but may
remain feeding in one area for several days. The female re-
mains wingless whereas the male develops wings, enabling flight.
Males pass through two nymphal stages (8.5 and 6.0 days, res-
pectively) a prepupal (2.1 days) and pupal (2.1 days) stage

before adults emerge.    Adult males live from 1-3 days.    There
is a sex ratio of one male to three females.

        Leuschner describes *P. manihoti* as probably being parthe-
nogenetic sicne no males have been observed in the field or
laboratory populations.    He reports that the female lays about
440 eggs during its life span.    Eggs hatch in about 8 days.
The duration of the numphal stages is about 25 days at 25°C
and the female adult life span is about 29 days.    The dry sea-
son appears to favor mealybug population buildups.


## Control

        Reports indicate that this pest may be difficult to con-
trol.    Albuquerque states that no insecticide gave complete
control but that parathion was most effective.    Biological con-
trol and host plant resistance studies have been initiated.
Several predators and parasites of *P. gossypii* have been collec-
ted at CIAT.    Predators include *Cleotera onerata*, *Cleotera* sp.,
*Scymus* sp., *Coccidophilus* sp., a Coccinellidae; the neuropteras
*Chrysopa arioles* and  *Sympherobius* sp.; the dipteran *Ocyptamus*
sp., (*stenogaster* Will. complex) and the lepidopteran *Pyroder-
ces* sp.    The only natural enemy of *P. manihoti* found in Zaite
was the predator lycaenid butterfly *Spalgis lemolea*.

## Insects that Attack Roots, Cuttings and Seedlings


## Grubs

        Grubs are pests of cassava all over the world and are re-
ported as a serious problem in Indonesia.    Although several
species are mentioned in the literature, *Leucopholis rorida*
(Indonesia) and *Phyllophaga* sp. [Colombia appear to be the most
important.    The adult stage of the grub is a beetle, usually of
the family Scaravaeidae or Cerambycidae.    Those reported in
literature include *Leocopholis rorida*, *Lipidiota stigma*, *Euchlo-
ra viridis*, *E. nigra*, *E. pulchripes*, *Anamala obsoleta*, *A. atcha-
ralis*,  *Phyllophaga* spp *Heteronychus plebejus*, *Opatrum micans*,
*Corphopilus margirellus*, *Dactylosternum* sp., *Inesida leprosa*,
*Petrognata gigas* and *Sternotomis virescens*.


## Damage

        White grub damage is characterized by the destruction of
the bark and buds of recently planted cuttings and the presence
of tunnels in the woody part.    These cuttings may rot and die.
When young plants (1-2 months) are attacked, they suddenly wilt

369

and die. Larvae will feed on bark of the lower stem just below the soil, roots and swollen roots.

Studies with *Phyllophaga* sp. at CIAT show that germination could be reduced by 95% in experimental plots; losses of 70% have been reported from Madagascar.

Life History, Appearance and Habits

The biology of *L. vorida* on cassava has been described in Indonesia. Adults become active after the rains have started, and the most severe damage occurs about 4-6 months later. The aduot beetles initiate oviposition about 9 days after mating, laying up to 37 pearly white eggs single, 50-70 cm deep in the soil. Larvae hatch in about 3 weeks. The larval stage is about 10 months, with the 4- to 6-month-old larvae being the most destructive. Larvae live about 20-30 cm deep in the soil where they feed on roots. Pupation takes place at a depth of about 50 cm. The prepupal stage is 14 days and the pupal stage is about 22 days. Additional hosts include maize, rice and sweet potatoes.

Observations of *Phyllophaga* sp. in Colombia indicate that there is a one-year cycle, with heaviest damage occurring at the onset of the rainy season. Attacks often occur if cassava is planted in land previously used for pasture or in a weedy, abandoned field. High populations can often be detected at the time of land preparation.

Control

Biological control.- Several larval parasites of the grub have been identified including several species of *Dielis* (*D. lectuosa*, *D. tristis*, *D. thoracica*, *D. javanica*, *D. formosa* and *D. annulata*). Parasitism in one study reached 26%. A muscardine fungus *Metarhizium anisopliae* is pathogenic to the grub, and recent experiments at CIAT indicate that this may be an effective control method. Diseased grubs have been found under natural conditions.

Chemical control.- White grubs were controlled with aldrin and carbofuran as a dust or in granular form applied below the cutting in the soil; insecticidal dip treatments for cuttings were not as successful.

## Cutworms

Cutworms, a universal pest, have been reported to attack cassava in the Americas and Madagascar. The species reported are *Proaenia litura* [ = *Hadema littoralis*] *P. eridania* [ = *Xylomyges eridania*] and *Agrotis ipsilon*.

## Damage

Cutworm damage to cassava can be grouped into three categories: (a) Surface cutworms, such as *A. ipsilon* and *P. litura*, chew off plants just above, at, or a short distance below the soil surface, leaving the plant lying on the ground. Plants will recover and cotninue to grow. A similar type of damage by crickets is reported. The larvae of *A. ipsilon* are greasy gray to brown, with faint, lighter stripes. (b) Climbing cutworms ascend the stem, feeding on buds and foliage; they may also girdle the stem, causing the upper part of the plant to wilt and die. Larvae of the southern armyworm *P. eridania* have been reported to cause this type of damage in cassava-growing areas. They are dark gray to black in color, with lateral yellow stripes. (c) Subterranean cutworms remain in the soil, feeding on roots and underground parts of the stem, causing a loss of planting material. The bark and buds may be completely stripped. We have also observed *A. ipsilon* attacking cuttings in Colombia.

Losses of young plants as a result of cutworm damage may reach 50% making it necessary to replant. In simulated damage experiments at CIAT, shoot removal of recently germinated cuttings showed that some varieties and shorter cuttings are more susceptible to this damage.

## Life History, Appearance and Habits

The biology of the cutworm species that attack cassava is similar. Eggs are laid in masses on the undersides of leaves near the soil. Eggs hatch in 6-8 days in develop in 20-30 days. The pupal stage (8-11 days) is passed in the soil or under plant debris. Oviposition is initiated about one week after adults emerge. A generation lasts about 2 months; under favorable environmental conditions, several generations will occur in one year.

371

## Control

Cutworm attacks are sporadic but occur more frequently when cassava follows maize or sorghum, or is planted adjacent to these crops. Longer cuttings will allow plants to recover from surface cutworm attack. Cutworms attacking plants at or above ground level may be controlled effectively with poison baits (10 Kg of bran or sawdust, 8-10 liters of water, 500 g of sugar or 1 liter of molasses, and 100 g of triclorfon for 0.25-0.5 ha). Underground cutworms can be controlled by application of aldrin or carbofuran around the cuttings.

## Termites

Termites attack cassava mainly in the tropical lowland. They are reported as pests in several areas of the world but primarily in Africa. *Coptotermes voltkowi* and *C. paradoxis* been identified from Madagascar. They feed on propagation material roots, swollen roots or growing plants. Principal damage appears to be loss of cuttings; plant establishment can also be affected severely, especially during prolonged dry periods.

In Colombia termites have been observed causing considerable losses in germination, as well as death of young plants, in several cassava-growing areas, especially where soils are sandy. In studies doen at CIAT nearly 50% of stored propagating material was lost due to termite feeding, and germination losses of 15-30% have been recorded. We have also observed swollen root damage by termites with subsequent root rot.

## Control

Propagation material can be effectively protected by dusting with aldrin, Clorvel or Sevin. Aldrin, applied as a dust at the rate of 1 g per cutting at the time of planting, prevented termite attack of germinating cuttings.

## Crickets

Crickets damage plants by clipping recently emerged young shoots or feeding on the base of the plant, making it more susceptible to lodging. *Gryllotalpa africana*, reported from West Africa, is described as cutting and piercing roots and basal parts of the stem. *Brachytripses ackatimes* has been reported from Malaya. Poison baits such as those described for cutworms appear to give effective control.

## Storage Pests of Dried Cassava

Approximately 38 insects, mainly Coleoptera, are reported as found on dried cassava chips or products. Many are polyphagous; only those able to reproduce on dried cassava are important. These include *Stegobium paniceum*, *Araecerus fasciculatus*, *Rhizopertha dominicana*, *Dinoderus minutus*, *Tribolium castaneum* and *Latheticus oryzae*. Most damage is reported from Asia and Africa, and on imported dried cassava in Europe.

No data are available on losses in dried cassava resulting from insects. Cassava chips were reduced to dust in 4-5 months in India. Recent studies at CIAT indicate that *A. fasciculatus*, the coffee bean weevil, and *D. minutus*, the bamboo powderdust beetle, can cause considerable losses.

## Life History, Appearance and Habits

Cotton, among others, gives detailed references and information on the biology of many of these storage pests. Indications are that died cassava roots are not a good nutritional medium for insects because they lack protein, vitamins and micronutrients.

## Control

Proper sanitary measures, such as cleaning and disinfecting warehouses prior to restocking and rapid removal of infested material, are the most effective control measures. Bitter varieties of cassava are reported to be more resistant to weevils than sweet ones; however, this needs confirmation. Standard grain fumigations also give effective control of these pests.

## Crop Protection

The recent interest in cassava as an energy source for human, animal and industrial needs is bringing about an increase in production of this crop, as well as a change in production technology. The need for a relevant and sound crop protection program takes on added importance. As previously stated, cassava has historically been cultivated on a small scale with several varieties being growin on one region or even on one farm. The genetic variability in this system toward large cassava plantations, employing a limted number of high-yielding hybrids or varieties. These varieties or hybrids are often ideal plant types; that is, efficient plants that will not produce excessive foliage as many traditional varieties do at pre-

sent. The reasonably stable equilibrium that presently exists between pest and genotype in subsistence agriculture will be almost impossible to maintain in modern agricultural systems.

The major objective of a cassava pest management program is to suppress insect pests and maintain populations below their economic threshold. This should be done with a minimal use of costly inputs, especially pesticides. The accomplishment of this goal requires greater knowledge than we now posses of the biology and ecology of many of these pests. Advantage should be taken of the favorable factors involving the insect/plant/environment interaction and socioeconomic considerations that make a cassava pest management system an attractive and practical goal. These factors include:

1. Cassava is cultivated from 8 to 24 months, making the continual use of pesticides costly.

2. Being a long-season crop, cassava is ideally suited for a biological control program, especially in areas where there is considerable acreage and continual planting of cassava. Biological control agents have been identified for many of the major pests.

3. The cassava plant is often able to recover from insect damage. During periods of adequate rainfall, high levels of defoliation can result in little or no yield reduction.

4. Many pests are not widely distributed and pest incidence is often seasonal. The dry periods favor population buildup of many pests, but the plant's ability to withstand long periods of drought will usually result in its recovery at the onset of rains.

5. Cassava has a high economic threshold; vigorous varieties can lose considerable foliage (40% or more), and there are periods when the plant can undergo much higher defoliation with no significant reduction in yield. However, the new varieties developed may have a lower tolerance to defoliation.

6. Few, if any, pests will actually kill the plant, enabling it to recover from damage and produce edible roots.

7. The selection of healthy, vigorous planting material, combined with a low-cost fungicidal and insecticidal treatment, initiates rapid and successful germination, ensuring early plant vigor during this important phase and ultimately increasing yield.

8. Studies have shown that there are sources of pest resistance in cassava which, although often low levels, may be

374

adequate to prevent serious crop losses.

9.  Cassava is often grown on small farms and under multi-cropping conditions; this system not only reduced pest inciden-ce but also ensures against pest outbreaks over extended areas.

10. Evidence is that insects can cause yield reduction during specific periods in plant development.  These periods should be identified so that control practices can be intensi-fied during this time.

Since cassava pest control has received only limited atten-tion until recently, few, if any, real trends or practices have become established over a wide area.  Cassava is a low-value crop in most areas, so the use of costly pesticides does not appear economically justificable; therefore, their application should be limited.  The mention in this paper of the use of pesticides for controlling cassava pests is not necessarily an endorsement of this practice.


The Role of Different Control Methods

There are several methods for reducing pest populations below their economic injury level.  An integrated control pro-gram utilizing cultural practices, selection of planting mate-rial, resistant varieties, biological control and alternative methods such as pheromones or attractants should be developed. Insecticides will be used because they offer the most immediate and rapid means of reducing pest populations over a short pe-riod.  However, it is strongly felt that no pest management program should be dependent upon pesticides and they should be used only as a last resort, on a short-time basis.  Nevertheless, trating planting material with pesticides is economical and effective for certain pests.

Insecticidal applications to cassava foliage may tempora-rily reduce pest populations, but indications are that they are ineffective over a long period as they may also reduce parasi-te and predator populations.  This can lead to rapid buildups of pest populations.  This can lead to rapid buildups of pest populations or to secondary pest (normally suppressed by natu-ral enemies) becoming more destructive.

There are several cultural practices that can reduce pest populations.  These include the use of insect-free planting material, the destruction of plant parts containing shoot flies, stemborers and scale insects, and the planting of several var-ieties on a single plantation.  The implementation and practi-cability of some of these practices may be reduced as more mo-dern agricultural technology is applied to cassava production.

Alternate means of control such as the use of pheromones, juvenile hormones, attractans and growth regulators are future possibilities and may be economically feasible on large cassava plantations: however, their use may be prohibitive for small grower.

Since many cassava pests are not widely distributed, especially from one continent to another, it is important that an efficient quarantine program be developed and enforced within and between continents. As new high-yielding hybrids are developed, there will be increased movement of planting material. Since cassava is vegetatively propagated, many insects and diseases can be transported from one are to another. Precautions should be taken to send only insect-and disease-free planting material, and all vegetative material should be treated with an insecticide to prevent the dissemination of insects such as scales, mites, mealybugs, thrips and other pests. Material should also be free of stemborers or fruit fly larvae.

We strongly feel that an integrated control program for cassava pest should be based on biological control and host plant resistance. These two links in an integrated control chain will play important roles in future cassava pest management programs. Extensive studies in both of these areas are being carried out for several cassava pests.

Biological Control

Numerous natural enemies have been identified and found efficient in reducing populations of cassava pests. Concentrated biological control studies for cassava pests are a rather recent effort: three systematic studies and consequent programs have been initiated. Bennett & Yaseen have evaluated the effectiveness of biological control of the mite *M. tanajoa* with the Staphylinidae *Oligota minuta*. Studies on the biological control of the mealybug *Phenacoccus manihoti* involve a collaborative program between the Commonwealth Institute of Biological Control in Trinidad, IITA and CIAT.

A program studyin the biological control of the cassava hornworm, *E. ello*, has been in effect for nearly six years at CIAT. This program combines egg and larval parasitism, larval predation and larval diseases.

Several other cassava pests offer the possibility of being controlled effectively by natural enemies. There are several parasities or predators of  scale insects; whiteflies, the gall nudge and fruit flies that have been identified and require further study. Preliminary studies at CIAT on control of the white grub (*Phyllophaga* sp.) using the muscardine fungus *Metar-*

376

*thizium anisopliae* are promising.

There is excellent potential for implementing biological control as a low-cost, environmentally sound and compatible component of a cassava pest management program.


Host Plant Resistance

Host plant resistance offers the most economical and environmental sound means of controlling cassava pests. Resistance to pests attacking cassava is not reported extensivelt in the literature; most reports deal only with field observations. Ongoing systematic evalautions of germplasm for pest resistance has been initiated at CIAT, IITA and several national research centers. Varying degrees of varietal resistance have been reported for mites, thrips, whiteflies, stemborers, and shoot flies. Cassava germplasm is presently being evaluated for resistance to mites, thrips, scales, mealybugs, whiteglies, fruit flies, and lace bugs.

The decision to identify and utilize host plant resistance fro specific cassava pests depends upon various criteria that should be taken into consideration when establishing a program of this nature. These criteria include:

1. The level of economic damage being caused by a particular pest should be significant.

2. Resistance should be sought only for those pests where it is considered feasible.

3. The availability of adequate, low-cost alternative of control of certain pests could negate the need for entering into an extensive resistance breeding program.

4. The levels of resistance needed to reduce pest populations below an economic injury level should be considered. Since some cassava varieties have a high economic thresfold, high levels of resistance may not be necessary.

5. Low levels of resistance can be combined with other control methods (i.e. biological control or cultural practices), to maintain insect populations below economic damage levels.

6. Multiple cropping systems may require lower levels of resistance since these systems may have reduced insect populations.

Cassava is a leafy, highly heterozygous naturally cross-pollinated, woody perennial. It has a long growth cycle and

377

is easily propagated by seed or cuttings. It is grown in a
scattered cultivation pattern with many traditional varieties
that have various degrees of susceptibility to insects and dis-
eases. These characteristics indicate that there is a minimum
of selective pressure being exerted by pests in cassava culti-
vation. Vertical resistance in terms of the gene-for-gene the-
ory would probably not evolve within such a system; therefore,
resistance is probably of the horizontal type, inherited multi-
genically. Resistance to major cassava diseases appears to
confirm this assumption. Since horizontal resistance is more
stable and entails less risk as to the development of biotypes,
cassava insect resistance studies should have horizontal resis-
tance as their goal.

A cassava pest management program should place emphasis
on combinations of three fundamental tactics: (1) host resis-
tance. (2) biological control, and (3) cultural control. It
is important to note that pest damage to the cassava plant
does not necessarily result in a yield reduction or loss of
quality of the harvested crop; therefore, control methods need
not to be applied unless there is an estimation of yield reduc-
tion. The ability of the cassava plant to recover from pest
injury is an important criterion that should always be taken
into consideration.

The Status of Cassava Entomological Research

Concentrated research in cassava entomology is recent.
At CIAT, for example, the research program is less tha 7 years
old, and a full-time entomologist has been assigned only for
the last 4 years. Few national goverments have cassava research
program,s and entomology seldom occupies a significant role in
any program that might exist.

We are presently confronted with an extensive range of
studies that needed to be done before an effective pest manage-
ment program can be developed. These studies should be orient-
ed towards a minimal use of pesticides and the development of
alternative control methods that will nor destroy the ecologic-
al balance between pests and parasites found in cassava planta-
tions. Emphasis should be placed on the following aspects: de-
termination of yiel losses and levels of economic injury for
the major pests or combination of pests; the role of the envi-
ronment and the influence of plant age on pest incidence and
severity of damage; studies on the biology and ecology of all
important pests, determining the most feasible control methods
(host plant resistance for mites, whiteflies, thrips, mealybugs;
biological control for hornworms, scales, white grubs, mites;
cultural practices for cutworms, fruit flies, shoot flies);
studies on potential pest problems that could occur if cassava

378

acreages increase and monocultures and continuous planting of cassava are practiced; investigation of the danger of major or secondary pests becoming increasingly important as high-yielding varieties are released; studies into alternative control practices such as attractans, pheromones, or insect-growth regulators; investigating pest problems during the storage of planting material and the establishment phase of the plant; and production of insect- and disease-free planting material (as the basis for an effective quarantine program, a worldwide survey should be undertaken to identify cassava pests accurately and establish their true distribution).

Since cassava entomological research is concentrated in only a few institutions, it is feasible to establish guidelines and recommendations for future research goals and the implementation of a pest management program. The time to do this is now while cassava entomological research is still in its infancy. In November 1977, a Cassava Protection Workshop, sponsored by CIAT brought together researchers and pest management specialists from all over the world to consider these problems.

THE CASSAVA MITE AND INSECT COMPLEX

| Common name | Important species | Reported from | Alternate hosts | Yield losses | Type of damage |
|---|---|---|---|---|---|
| White grubs | *...* sp. | All regions but mainly Americas and Indonesia. | Numerous | 95% loss germination | Feed on planting material and roots |
| Termites | *...* | All regions but mainly Africa | Numerous | Unknown | Tunnel in planting material roots, stems and swollen roots. |
| Cutworms | *...* | Americas and Madagascar | Numerous | 60% loss germination | Feed on planting material, girdle stems and consume foliage |
| Scales | *...* | All cassava-growing areas | Unknown | (a) 20%, (b) 50-60% loss in germination | Attack stems, which dry, causing leaves to fall. (b) Use of infested stems reduces germination of planting material |
| Fruit flies | *...* | Americas | Unknown | (a) Unknown, (b) 25-30 | (a) Boring of fruit, seeds and stems, causes rotting of pith area, (b) Use of infested stems for planting material results in yield loss. |
| Cassava hornworm | *...* | Americas | Manioc + ? oak, poinsettia, rubber, pepper, milkweed | 20%-63% one and two attacks | Foliage, tender stems and buds consumed |
| Grasshoppers [2] | *...* | Mainly Africa | Numerous | Unknown | Defoliation and stripping of bark |
| Leaf-cutter ants [2] | *...* sp. | Americas | Numerous | Unknown | Remove foliage |
| Mites [3] | *...* | Americas and Africa | *...* sp. | Up to 82 | Leaf defoliation and deformation, heavy yield reduction or death |
| | *...* | All regions | Numerous | Unknown | Leaf necrosis and defoliation |
| | *...* | Americas | 53% | | Leaf spotting and defoliation |
| Whiteflies [3] | *...* | Africa, Asia | Numerous | Unknown | Vector of African cassava mosaic |
| | *...* sp. | Americas | Unknown | Up to 79% | Severe mottling or curling of leaves, presence of sooty mold |
| Mealybugs [3] | *...* | Americas Africa | Numerous | Up to 86% | Foliage and stems attacked, causing stem drying and leaf fall |
| Lace bugs [3] | *...* | Americas | Unknown | Unknown | Leaves with yellow spots that turn reddish brown |
| Thrips [4] | *...* | Mainly in Americas but also in Africa | Unknown | 6-28% | Deformation of foliage, death of buds and browning of stem tissue. |
| Gall midges [4] | *...* | Americas | Unknown | Unknown | Yellowish green to red galls formed on upper leaf surface |
| Stemborers [5] | *...* sp. | All regions but mainly Americas | Unknown | Unknown | Boring into and tunneling into stems and occasibly swollen roots |
| Shoot flies [5] | *...* | Americas | Manihot spp... *...* sp. *...* sp | Up to 34% | Larvae bore into and kill apical buds, causing plant deformation and stunting |

1 Insects attacking planting material
2 Insects attacking the growing plant, foliage consumers
3 Sap-sucking insects and mites
4 Leaf deformers
5 Bud and stem borers

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# THE MEALIBUG AND CASSAVA GREEN SPIDER MITE COMPLEX

## IN THE AMERICAS: PROBLEMS OF AND POTENTIAL FOR

## BIOLOGICAL CONTROL

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INTRODUCTION

Cassava (*Manihot esculenta*) is a long-season crop; it is cultivated from 8 to 24 months depending upon environmental conditions. This long production cycle, together with the fact that most cassava farmers are traditional farmers with limited technical knowhow and few economic resources, makes the continual use of chemical pesticides impractical and uneconomical. The cassava plant has a high economic threshold and is often able to recover from insect damage. In addition, studies show that there are sources of pest resistance in cassava which, although often at low levels, may be adequate to prevent serious crop losses. The above facts indicate that integrated control of cassava pests is a feasible and practical goal. Biological control, the use of natural enemies, is an essential and integral part of a pest management system in cassava.

Numerous natural enemies of cassava pests have been identified; at CIAT more than 140 parasities, predators, and pathogens have been recorded Historically the use of pesticides in cassava plantations has been minimal; this occurred in the Americas primarily because an equilibrium exists between the plant (the traditional or landrace cassava variety), the pest, its natural enemies, and the environment. This equilibrium ensures against pest outbreaks over extended areas. However, there is sufficient current evidence to show that mites and insects can and do reduce cassava crop yields; the average yield of cassava

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in the Americas is only about 10 t/ha.  There is no doubt that
the extensive complex of insects and mites found attacking cas-
sava in the Americas (Bellotti and Schoonhoven, 1978) is restric-
ting cassava yields.  However, devastating pest outbreaks, com-
pletely destroying large areas of cassava, seldom occur.

This is due to several reasons:  (1) although most cassa-
va pests are widely extended throughout the cassava-growing re-
gions, farmers have been able to select cassava varieties that
are partially resistant or tolerant to important pests; (2) sev-
eral cassava varieties are planted in each region throughout the
whole or most of the year; some farmers will plant 10 or 12 ge-
netically different landrace varieties.  This diversity of ge-
notypes insures against epithytotics or pest ourbreaks; (3) an
abundance of natural enemies to many cassava pests that helps
maintain may pests in balance and prevents continual outbreaks;
(4) cultivation of cassava is usually in association with other
crops, which helps reduce pest populations.

Mites and mealybugs constitute two major pest groups at-
tacking cassava both in the Americas and in Africa.  The effec-
tive control of these pests will involve a pest management pro-
gram that contains the use of natural enemies as one of its ma-
jor components.  This paper will discuss the potential of bio-
logical control in mealybug and mite pest management systems.

THE PROBLEMS OF MITES AND MEALYBUGS IN THE AMERICAS

An analysis of the *Mononychellus* mite and mealybug problem
as it occurs in the Americas shows two distinct situations and
two different problems.

Mites

The  *Mononychellus* mite is a traditional pest of cassava;
it is found everywhere that cassava is grown.  It has been as-
sociated with the cassava crop for many centuries (perhaps
thousands of years).  Several species comprise the *Mononychellus*
mite complex, including *M. tanajoa*, *M. progresovus*, *M. caribbea-*
*nae*, *M. manihoti*, *M. Magregori*, and *M. bondari* (Flechtmann,
1977; Doreste, 1981).  *M. tanajoa* is probably the most widely
dispersed and important species in this complex, although a
recent taxonomic revision of the complex in Venezuela (Doreste,
1981) introduces somre doubt as to its exact geographic distri-
bution.  Doreste has broadened the complex to include two new
species, *M. progresivus*    *M. manihoti*.  He determined that
what was previously identified as *M.tanajoa* is actually two
species, *M. tanajoa* and *M. progresivus*.  It appears that *M. pro-*
*gresivus* and *M. tanajoa* are closely related species; a complete

394

collection and identification needs to be done to determine
the exact geographic distribution of each species.

The world "*tanajoa*" has its origin with the Indian tribes
of Brazil; it means diseased or sick.   A cassava plant with
"*tanajoa*" was considered a diseased or sick plant; actually, it
is a plant with a sickly or diseased appearance that has been
attacked by mites.  This is a further indication that the *Mono-
nychellus* mite has been  in association with the cassava crop
for some time.  Many of the landrace or traditional varieties,
especially in areas where this mite is a potential pest, have
at least some low levels of resistance or tolerance to the mite
and seldom are cassava plantations devastated by it.   Because
of the existing equilibrium between the traditional varieties,
the mite, and its natural enemies, root yield is always assured;
at times, the yield may be low.  Plants, however, are seldom
killed, and yield is usually stable over time.

Yield losses due to mites in the Americas, therefore, are
difficult to measure.  In experiments with protected and unpro-
tected treatments in plots, yield losses of 8 and 17% (Doreste
and Aponte, 1978) with local varieties were reported from Vene-
zuela.  In Colombia, root losses were 73% on susceptible vari-
eties but only 15% on resistant varieties (Byrne *et al*, 1982).
In experiments with treated vs. untreated plots using a local
farmer variety at the Centro Nacional de Pesquisa en Mandioca
y Fruticultura in Bahia, Brazil, a 3-year study resulted in no
yield losses due to mite attack.  In Colombia, root yield los-
ses of 20 to 50% were observed with a complex of four mites
(*Tetranychus urticae, M. tanajoa, M. Mcgregori, Oligonychus pe-
ruvianus*) and varying timing and duration of attack (CIAT, 1977).
These, however, are experimental results and not necessarily a
measure of actual losses being felt by farmers with traditional
varieties.  Observations indicate that traditional varieties,
being grown by traditional cassava farmers in areas of poten-
tial mite problems, contain some levels of resistance to the
*Mononychellus* mite or, at least, are not highly susceptible to
mites.

Mealybugs

The situation described above for mites is very distinct
from that which presently exists for mealybugs.  There are sev-
eral species of mealybugs that feed on cassava belonging to the
genus *Phenacoccus;* the most important include *P. herreni, P. ma-
nihoti, P. gossypii,    P. grenadensis*.  This paper deals pri-
marily with *P. herreni* since, at present, it is causing the
most severe damage.

Mealybug damage to cassava is a recent phenomenon; it is
causing damage in areas where it was not previously found.  In
these areas the mealybug is an introduced pest, and the equili-
brium between the landrace variety, the pest, and its natural

enemies that exists with mites does not exist for mealybugs.
*P. herreni* is acting as an introduced pest in several areas
of the Americas just as *P. manihoti* is an introduced pest in
Africa.  *P. herreni* outbreaks in Pernambuco, Brazil, have been
severe because the local varieties are very susceptible and suf-
civient natural enemies do not exist to effectively reduce
mealybug populations.  Environmental conditions, including a
prolonged dry season, are favorable for population build-ups.
Traditional farmers have not had the opportunity to select var-
ieties resistant or tolerant to *P. herreni*; consequently, yield
losses are high (estimated to be more than 80% by the local far-
mers) and alternative crops are replacing cassava.

The first problem, then, is a traditional pest that has
been with us for centuries and is widely distributed with its
natural enemies also widely distributed.  Landrace varieties of
cassava are tollerant or resistant to mites but are susceptible
to an introduced pest, the second problem, which has become im-
portant only in recent years and is localized in its area of
attack.


POTENTIAL FOR BIOLOGICAL CONTROL


*Mononychellus* mites

A literature survey for natural enemies of cassava mites
resulted in 32 different predators and fungi (Table 1) in the
neotropics.  These include 16 different predator mites (*Acari-
na: Phytoleiidae, Blastisooidae,* and *Tydeidae*), five *Oligota*
species (*Coleoptera: Staphylinidae*), and two *Stethorus* species
and one *Delphastus* species *Coleoptera: Coccinellidae*).  The
*Phytoseiid* mites, the *Stethorus* beetles, and the  *Oligota* beet-
les are specialized mite predators; these should be more reli-
able and better able to maintain mites at lower densities than
generalized predators (Huffaker *et al*, 1970).

The actual effectiveness of mite predators in containing
cassava mite propulations is not well documented.  The *Phytosei-
ids* are generally considered better at controlling mites at low
levels than are insect mite predators.  Their persistent presen-
ce on plants when mite densities are low contrasts with the
larger insect predators that tend to migrate from the field or
plants at low mite densities.  The potential of *Phytoseiids*
for controlling cassava mites appears promising; however, re-
search on these predators and their effectiveness in reducing
mite populations has been limited.  Although these predator mi-
tes have been estimated to have a lower intrinsic rate of in-
crease than the *Mononychellus* mite (Yaseen and Bennett, 1977),
they are regularly associated with, and seem to influence, the
rate of population growth of the mite (Girling *et al*, 1978).

TABLE 1. PREDATORS AND PATHOGENS OF PHYTOPHAGUS MITES FEEDING ON CASSAVA IN THE AMERICAS

| Natural Enemies | Mite Associated with | Registered in | Reference |
|---|---|---|---|
| *ARACHNIDA* | | | |
| PARASITIFORMES: PHYTOSEIIDAE | | | |
| *Amblyseius largoensis* | *Mononychellus tanajoa* | Tobago | Yaseen & Bennett, 1978 |
| *Euseius coreomilia* | *M. tanajoa* | Paraguay, Tobago | Yaseen & Bennett, 1978 |
| *E. flechtmani* | *M. tanajoa* | Brazil | Farias *et al*, 1979 |
| *E. hibisci* | *M. caribbeanae* | Bahamas | Yaseen & Bennett, 1978 |
| *E. sibelius* | *M. tanajoa* | Brazil | Farias *et al*, 1979 |
| *Galendromus annectens* | *M. tanajoa* | | |
| | *M. caribbeanae* | Colombia | Moraes *et al*, 1982 |
| *G. longipilis* | *M. caribbeanae* | Colombia | Moraes *et al*, 1982 |
| *Neoseiulus anonymus* | *M. tanajoa* | | |
| | *M. caribbrarae* | | |
| | *Tetranychus urticae* | Colombia | Moraes *et al*, 1982 |
| | *T. cinnabarinus* | | |
| *N. idaeus* | *M. tanajoa* | Brazil | Farias *et al*, 1979 |
| *Phytoseiulus macropilis* | *M. tanajoa* | Perú | Yaseen & Bennett, 1978 |
| | *T. urticae* | Brazil | Samways, 1979 |
| | *T. cinnabarinus* | Brazil | Samways, 1979 |
| *Typhlodromalus aripo* | *M. progresivus* | Colombia | CIAT, 1982 (unpublished) |
| *T. horatti* | *M. tanajoa* | Brazil, Guyana, Surinam | Yaseen & Bennett, 1978 |
| *T. limonicus* | *M. tanajoa* | Colombia Mexico, Guyana | Yaseen & Bennett, 1978 |
| *T. rapax* | *M. tanajoa* | Colombia, Trinidad | Yaseen & Bennett, 1978 |
| *T. clavicus* | *M. tanajoa* | Brazil | Denmark & Muma, 1973 |
| *Typhlodromina* sp. | *M. tanajoa* | Colombia | CIAT, 1980 |
| INSECTA | | | |
| COLEOPTERA: *COCCINELLIDAE* | | | |
| *Stethorus* sp. | *T. urticae* | Trinidad | Yaseen & Bennett, 1978 |
| *S. darwini* | *M. tanajoa* | Guyana, Surinam | Yaseen & Bennett, 1978 |
| *Stethorus* prob. *darwini* | *M. tanajoa* | Brazil | Farias *et al*, 1979 |
| *Delphastus argentinus* | *M. tanajoa* | Guyana, Surinam | Yaseen & Bennett, 1978 |
| COLEOPTERA, *STAPHYLINIDAE* | | | |
| *Oligota* sp. | *M. tanajoa* | Brazil | Farias 1979 |
| *O. barbadorum* | *M. tanajoa* | Barbados | Yaseen & Bennett, 1978 |
| *O. centralis* | *M. tanajoa* | Colombia, Mexico Peru | Yaseen & Bennett, 1978 |
| *O. minuta* | *M. tanajoa* | Antigua, Bahamas Colombia, Guyana Monserrat, Peru St. Kitts, Surinam Trinidad & Tobago | Yaseen & Bennett, 1978 |
| *O. minuta* | *M. tanajoa* | Colombia, Mexico, Peru | Yaseen & Bennett, 1978 |
| DIPTERA, *CECIDOMYIIDAE* | | | |
| *Feltiella* sp. | *M. tanajoa* | Bahamas, Mexico Monserrat | Yaseen & Bennett, 1978 |
| *Feltia* sp. | *M. tanajoa* | Mexico | Yaseen & Bennett, 1978 |
| NEUROPTERA. CHRYSOPIDAE | | | |
| *Chrysopa* sp. | *M. tanajoa* | Uganda | Kylira, 1975 |
| | *T. urticae* | Colombia | CIAT, 1980 (unpublished) |
| THYSANOPTERA: *PHLAEOTHRIPIDAE* | | | |
| Unidentified | *M. tanajoa* | Trinidad | Yaseen & Bennett, 1978 |
| PATHOGEN | | | |
| *Hirsutella thompsonii* | *Oligonychus* | Colombia | CIAT, 1981 |
| Unidentified | tetraniquidos | Venezuela | Doreste, *et al*, 1978 |

397

TABLE 3. POPULATION FLUCTUATION AND DISTRIBUTION OF THE *MONONY-CHELLUS* MITE PREDATOR *OLIGOTA MINUTA* ON CASSAVA PLANTS (MCol 113) AT CIAT, COLOMBIA, DURING 1978*

| Leaf position (from top to botom of plant | Average number of *Oligota* adults per 48/leaves* | | | | Daily average No. of adult per 48/leaves |
|---|---|---|---|---|---|
| | 6 am | 9 am | 1 pm | 4 pm | |
| 1 | 0.88 | 0.25 | 0.55 | 1.07 | 0.69 |
| 2 | 7.00 | 1.72 | 2.13 | 2.57 | 3.36 |
| 3 | 14.4 | 6.5 | 7.7 | 8.83 | 9.36 |
| 4 | 14.4 | 11.8 | 12.8 | 15.0 | 13.5 |
| 5 | 25.0 | 16.3 | 19.2 | 17.8 | 19.58 |
| 6 | 21.9 | 18.5 | 19.8 | 20.0 | 20.05 |
| 7 | 19.5 | 19.8 | 21.0 | 19.8 | 20.03 |
| 8 | 13.6 | 18.0 | 18.04 | 16.6 | 16.65 |
| 9 | 12.8 | 16.4 | 14.4 | 13.6 | 14.3 |
| 10 | 10.2 | 12.9 | 12.3 | 10.6 | 11.5 |
| 11 | 7.1 | 10.2 | 9.9 | 8.2 | 8.85 |
| 12 | 4.7 | 8.0 | 5.8 | 5.9 | 6.10 |
| 13 | 3.5 | 6.7 | 5.5 | 4.8 | 5.13 |
| 14 | 2.5 | 5.4 | 3.7 | 4.3 | 3.98 |
| Average per leaf per time of day | 11.25 | 10.86 | 10.94 | 10.68 | 10.93 |

* an average of 42 days of sampling

TABLE 2.   OCCURANCE OF *OLIGOTA MINUTA* AND *STETHORUS* SP. IN FIELD POPULATIONS OF *M. TANAJOA* AND *T. URTICAE*

| Species | Total leaves examined | No. life stages of predator | | | | | |
| | | Stethorus sp. | | | Oligota minuta | | |
| | | Larva | Pupa | Adult | Larva | Pupa | Adult |
|---|---|---|---|---|---|---|---|
| **FIRST SAMPLE** | | | | | | | |
| *Tetranychus* sp. | 5450 | 240 | 235 | 273 | 2 | 0 | 45 |
| **SECOND SAMPLE** | | | | | | | |
| *Tetranychus* sp. | 3264 | 1953 | 871 | 357 | 7 | 0 | 5 |
| *Mononychellus* sp. | 4080 | 0 | 0 | 49 | 3 | 0 | 368 |

They live and oviposit among mite colonies and feed on the eggs and developmental stages. No studies have been done on *Phytoseiids* capacity for feeding on the *Mononycnellus* mite in the Americas. However, *Typhcodromulus rapax* and *T. limonicus* are described as the most effective predators (Yaseem amd Bennett, 1977; Girling *et al*, 1978).

The coleopteran predators, *Oligota* and *Stethorus*, are the most closely associated with cassava mites. Several species of *Oligota* have been reported feeding on mites in the Americas (Bennett and Yaseen, 1975; Yaseen and Bennett, 1977). Adults oviposit among mite colonies on cassava, and both larvae and adults feed on all mite stages. The larval stage of *O. minuta* is about 10 days and the developmental time of egg to adult is about 17 days. This relatively short life cycle allows this predator to synchronize well with the *Mononychellus* mite. The larval stage of *Oligota* can consume between 49 and 70 mites and from 44 to 61 eggs; in the adult stage, during a 7-to 16-day period, a total of 97 to 142 eggs and mites are consumed (Yaseen and Bennett, 1976).

Research at CIAT has shown tha the predator *Stethorus* sp. is most closely associated with mite populations of *Tetranychus urticae* and *T. cinnabarinus*. Preferences of *O. minuta* and *Stethorus* sp. for *M. tanajoa* and *T. urticae* were studied in the field by surveying predator number during periods of high populations of mites. In *T. urticae* populations, 98% od the predators are *Stethorus* vs. 2% for *O. minuta*, whereas in *M. tanajoa* populations, 88% are *Oligota* vs. 12% of *Stethorus* (Table 2). These results indicate a strong preference between the predator species and questions the importance of *Stethorus* sp. as an effective predator of the *Mononychellus* mite.

The *Oligota* predator, however, shows a strong preference for preying on the *Mononychellus* mite and consequently has more potential in a biological control program. Its population are well synchronized with the mite; a study of *O. minuta* distribution in a plant and its population fluctuation throughout the day was done at CIAT. Predator adults were counted at 6 a.m., 9 a.m., 1 p.m., and 4 p.m. High populations of *Oligota* did not fluctuate significantly during the day (Table 3). Within the first 14 leaves (top to bottom) sampled, the greater predator populations were on the fifth to eight leaves. This corresponds to the area of greatest mite populations, especially the *Mononychellus* mite which orefers feeding on the upper leaves; *T. urticae* has a preference for the lower leaves of the cassava plant (CIAT, 1980). Results also show that there is little movement of *O. minuta* during the day when mite populations are high.

Populations of *O. minuta* in cassava fields tend to fluctuate according to mite densities. During an 8-month study at CIAT, populations of the *Mononychellus* mite and *O. minuta* were monitored on a regular basis. Generally, oredator populations

400

were highest when mite populations were also high and all but disappeared when mite populations diminished (Table 4). The survey was done on var. MCol 22, which is susceptible to the *Mononychellus* mite; the damage grade during the period of study did not go above 3.8 (0-5 scale) and an overall average of 2.9, which is in the intermediate range. However, it should be noted that mite populations at CIAT are usually not very high. *O. minuta* does not maintain itself well at low mite (*Mononychellus*) densities and must, at times, migrate to other plants infested with mites to survive periods of low prey populations on cassava. Their value as predators lies in their relatively rapid development, good reproductive ability, and synchronization with mire populations in the field. However, our observations indicate that this predator does not prevent the build-up of mite populations and only appears in great numbers when mite populations are already high. This questions the value of *Oligota* in regulating *Mononychellys* mite populations.

An ideal sitation would involve a combination of *Phytoseiid* mite predators, which are better at controlling mites at low levels, with *Oligota* which appears to function well at higher mite densities. The use of mite-resistant cassava varieties in a pest mangement program offers another dimension. Resistant varieties generally have lower mite densities than susceptible ones, and mite population build-up are usually delayed; this could give the natural enemies a comparative advantage in maintaining mite populations below economic injury levels.


## Cassava Mealybugs

In general, the biological control of mealybugs on agricultural crops has been successful (Debach, 1964). The potential for successful control of cassava mealybug with natural enemies exists. There are an abundant number of variety of natural enemies associated with populations of cassava mealybug (Table 5); these include predators, parasites, and pathogens. Approximately 25 parasites of *Phenacoccus gossypii*, *P. herreni*, *P. manihoti* have been registered in the Americas.

Of these 21 are in the *Encyrtidae* family and include the genera *Anagyrus*, *Apoanagyrus*, *Aenasius*, and *Acerophaga*. The fungal pathogen *Cladosporium* sp. has recently been identified parasiting *P. herreni* in both Brazil and Colombia.

Approximately 43 predators have been reported predating on the above-mentioned mealybug species. Most of these belong to the family *Coccinellidae*, primarily of the genera *Hyperaspis* and *Nephus*. Insect orders represented include *Neuroptera* (four *Chrysopa* species and two *Sympherobius* sp). Table 5 lists 69 natural enemies of these mealybugs. Most of these species have been reported from cassava fields, as noted in the table. Some have been found on these mealybugs, especially *P. gossypii* on

TABLE 4. THE POPULATION OF THE *MONONYCHELLUS* MITE AND ITS PREDATOR *OLIGOTA MINUTA* ON THE CASSAVA VARIETY MCOL 22 FROM JANUARY TO AUGUST 1979 AT CIAT COLOMBIA

| Date of sample | Mites/leaf | | *Oligota* predators/40 leaves | | | Damage[1] grade |
|---|---|---|---|---|---|---|
| | Eggs | Nynphs & adults | Eggs | Larvae | Adults | |
| 29 Jan. | 519 | 226 | 129 | 10 | 11 | 2.9 |
| 5 Feb. | 1009 | 830 | 191 | 71 | 27 | 3.0 |
| 12 Feb. | 141 | 320 | 26 | 11 | 5 | 3.4 |
| 19 Feb. | 378 | 177 | 23 | 2 | 4 | 3.5 |
| 26 Feb. | 595 | 497 | 37 | 2 | 1 | 3.5 |
| 5 Mar. | 276 | 599 | 26 | 5 | 2 | 3.3 |
| 12 Mar. | 223 | 668 | 71 | 10 | 9 | |
| 20 Mar. | 165 | 444 | 35 | 5 | 7 | 3.7 |
| 26 Mar. | 174 | 458 | 11 | 6 | 8 | |
| 2 Apr. | 627 | 422 | 64 | 9 | 10 | 3.8 |
| 18 Apr. | 278 | 458 | 197 | 17 | 40 | 3.6 |
| 30 Apr. | 152 | 307 | 5 | 2 | 9 | 2.6 |
| 14 May. | 137 | 217 | 11 | 3 | 12 | |
| 28 May. | 79 | 23 | 0 | 0 | 5 | 1.8 |
| 11 Jun. | 75 | 12 | 2 | 0 | 1 | 0.2 |
| 26 Jun. | 37 | 21 | 3 | 1 | 1 | |
| 10 Jul. | 340 | 95 | 53 | 4 | 19 | 1.4 |
| 24 Jul. | 113 | 126 | 35 | 10 | 3 | 3.7 |
| 13 Jul. | 130 | 150 | 35 | 10 | 3 | 3.7 |
| TOTAL | 5448 | 6050 | 954 | 173 | 182 | |
| Average | 287 | 318 | 50 | 9 | 10 | 2.9 |

1 Based on 0-5 damage scale

402

TABLE 5.  RECORDS OF HYPERPARASITES OF *PHENACOCCUS* SPP. IN LATIN
AMERICA. - PART III

| III. Hyperparasites | Beneficial species hyperparasi- tized |
|---|---|
| *Prochiloneurus dactylopii* (How) | *Apoanagysus lopezi* *Aenasius phacocci* *A. vexans* |
| *Prochiloneurus argentinensis* | ? |
| *Prochiloneurus* sp. | *Anagyrus* *Aenasius phenacocci* |
| *Chartocerus* sp. | ? |
| *Pachyneuron* sp. | *Ocyptamus* *Leucopis bella* |
| *Thysanus* sp. | *Anagyrus pseudococci* *Aenasius masii* |
| *Achrysopophagus* sp. | *Anagyrus pseudococci* *Aenasius masii* |

other crops.

Two species of mealybugs and their potential biological control in the Americas will be further discussed; they are *P. herreni* and *P. gossypii*. They present two distinct situations; their mode of attack is different and cassava is not the preferred host of *P. gossypii*, whereas it appears to be so for *P. herreni*, *P. gossypii* will be discussed first.

*P. gossypii* has numerous natural enemies (Table 5); its mode of attack is such that its populations are well exposed (on the tender portion of the stems and on leaf undersurfaces) and accessible to predation and parasitism by natural enemies. In studies at CIAT (1979), cassava cultivars were infested at 45 days with six *P. gossypii* egg masses and protected in screened cages to prevent attack by natural enemies. Counts showed that 44.9, 41.0 and 14.1% biological stages were found on the basal, middle and upper third of the plant, respectively. The effectiveness of several enemies on controlling *P. gossypii* was studied on cassava plants growing in field cages (CIAT, 1980). When mealybugs became very numerous (about 26,000 nymphs and adults per cage) natural enemies were allowed entry. Predator and parasite populations were recorded for 6 weeks, by which time mealybug populations were almost zero.

In general, there was a higher percentage of predation than parasitism, but the latter never averaged more than 10%. Predation of ovisacs, principally by *K. coccidarum*, reached 100% after 5 weeks, and predation of nymphs and adults reached 96%, primarily due to *Chrysopa* and *Reduviids* (Table 6). Major predators were *Chrysopa*, *K. coccidarum*, and several *Coccinellids* and *Reduviids*; *Anagyrus* spp. were the predominant parasites (Table 7). In cages where mealybugs were most numerous, *K. coccidarum* was the heaviest predator while *Chrysopa*, and *Reduviids* and some *Coccinellids* predominated in cages with lower mealybug populations. Mealybug populations decreased steadily during the 6 weeks (Fig. 1).

High populations of the dipteran predator *K. coccidarum* have been observed in greenhouse colonies of both *P. gossypii* and *P.herreni*. However, field populations have been erratic. *K. coccidarum* appears more frecuently when field populations are high. This predator was initially observed predating on eggs withing the ovisac, but larvae have also been found predating on nymphs, especially adult females, when ovisacs are available. It remains in the ectoparasitic stage and seldom causes nymphal mortality until the ovisac is formed, when it then predates on eggs until completing its life cycle. Its ectoparasitic stage is important for survival when host populations are low. A female: male ratio of 2:1 was observed. The average number of *K. coccidarum* per ovisac varied depending on host availability; when ovisacs were numerous, an average of
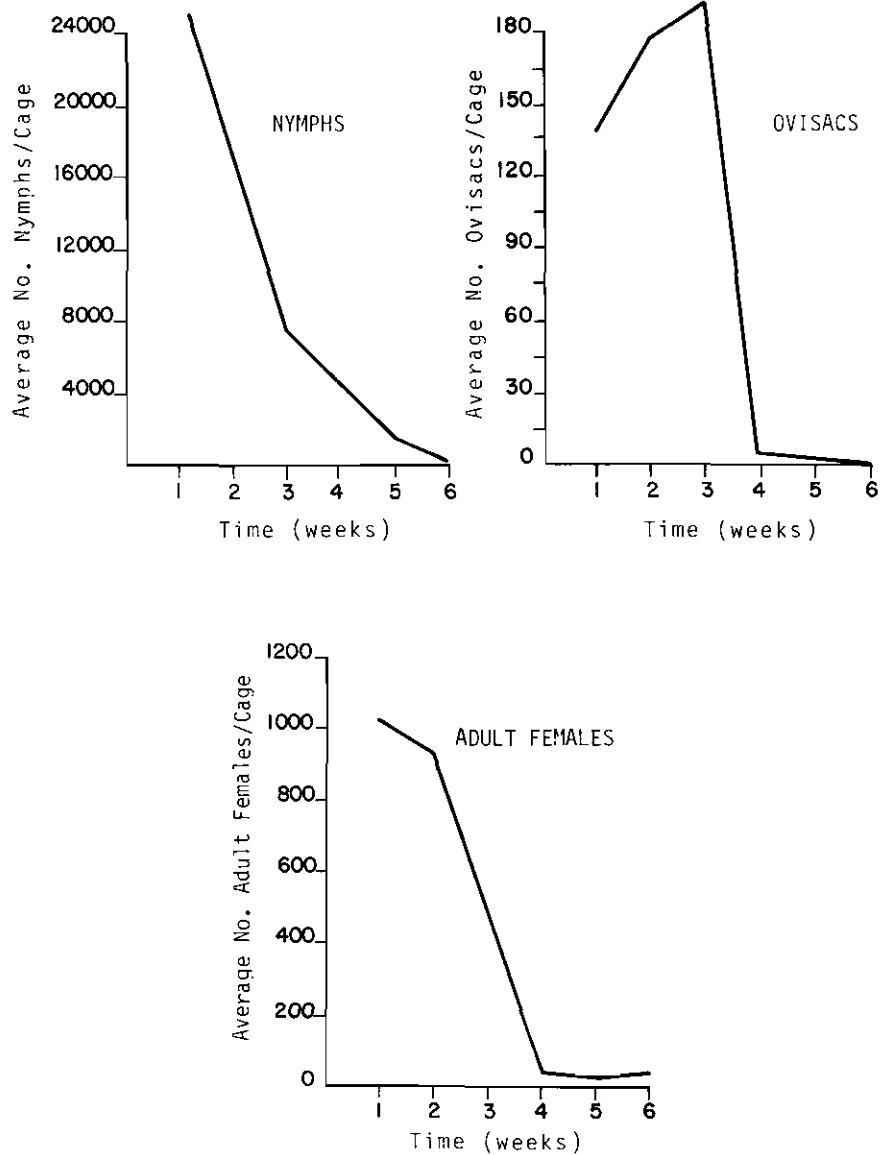
FIGURE 1.  REDUCTION IN NUMBER OF OVISACS, NYMPHS AND ADULT FEMALES
OF *Phenacoccus gossypii* BY ITS NATURAL ENEMIES.

TABLE 6. PREDATION[1] AND PARASITISM[2] OF THE MEALYBUG *PHENACOCCUS GOSSYPII* FEEDING ON CASSAVA BY NATURAL ENEMIES OVER FIVE CONSECUTIVE WEEKS IN FIELD CAGES[3].

| Weeks after exposure to natural enemies | % predation of ovisacs | % predation of nymphs and adult-females | % parasitism of nymphs and adult-females |
|:---:|:---:|:---:|:---:|
| 1 | 64.4 | 76.6 | 5.1 |
| 2 | 78.4 | 94.6 | 4.8 |
| 3 | 94.6 | 87.9 | 8.8 |
| 4 | 96.6 | 70.6 | 6.7 |
| 5 | 100 | 73.2 | 9.6 |

1     Predators = *Kalodiplosis coccidarum, Chrysopa coccinelidae* and Reduviidae

2     Parasite = *Anagyrus* sp.

3     Field cages = 3x3x2 meters

TABLE 7. POPULATIONS OF FIVE NATURAL ENEMIES OBSERVED ATTACKING MEALYBUG (*PHENACOCCUS GOSSYPII*) POPULATIONS ON CASSAVA OVER FIVE CONSECUTIVE WEEKS IN 6 EXPOSED FIELDS CAGES[1]

| Weeks after exposure to natural enemies | Average number of natural enemies per cage[2] | | | | |
|---|---|---|---|---|---|
| | Predators | | | | Parasites |
| | *Kalodiplosis coccidarum* | *Chrysopa* sp. | Coccinellidae | Reduviidae | *Anagyrus* sp. |
| 1 | 492.0 | 33.3 | 61.0 | | 17.5 |
| 2 | 40.5 | 27.8 | 20.7 | 35.7 | 8.3 |
| 3 | 50.0 | 30.0 | 28.3 | 10.0 | 2.3 |
| 4 | 11.7 | 23.8 | 2.3 | 12.0 | 0.2 |
| 5 | 2.3 | 18.7 | 3.2 | 7.0 | 0.2 |

1 Field cages 3x3x2 meters

2 Average per cage for 6 cages

three predator larvae were found per ovisac (from 1-5) and
higher predator populations resulted in five larvae per ovisac
(range 2-8). Initial studies of *K coccidarum* indicate a life
cycle of 12 days (at 28°C) to 16 (at 22°C).

In recent years, studies at CIAT have concentrated on the
*P. herreni* mealybug species since this is of greater economic
importance. Natural populations of this mealybug were studied
in cassava fields at CIAT. During 1981, systematic evaluations
of populations of its natural enemies were made by collecting
infested plant parts from 13 locations and identifying emerging
parasites and predators. Collections were made during July,
August, and September when mealybug populations were highest.
Five major natural enemies were identified (Table 8). *Ocypta-*
*mus* was by far the most predominant predator accounting for 68%
of the total natural enemies observed and was found in 85% of
the fields surveyed. Other predators collected were of the ge-
nera *Cleothera*, *Sympherobius*, and *Chrysopa*. *Anagyrus* sp. was
the major parasite collected and accounted for 19.2% of the
enemies collected.

During September 1982, similar evaluations were initiated.
A variety of natural enemies was collected (Table 9). In the
first sampling, 13 predator species were identified and in the
second sampling 12. The predator collected in greatest numbers
was *K. coccidarum*; this predator did not appear in the 1981
sampling. The most prominent parasite found was the micro-hy-
menopteran *Acerophaga coccois*. This parasite represented 86%
of the parasites collected in the first sample and 92% of those
in the second. Although this parasite was collected in previous
years at CIAT, it was not collected in such high numbers. A
colony of this parasite has been established and further studies
are planned.

During a *P. herreni* outbreak in Pernambuco, Brazil, sever-
al predators and parasites were collected. Predatos included
the dipterans *Ocyptamus* ap. and a *Cecidonyiidae* (possibly *Kalo-*
*diplosis*); the Coleopterans, *Hyperaspis notata*, *Hyperaspis* sp,
and *Nephus* sp; a *Chrysopa* sp; a *Caribidae*; the *Reduviidae*, *Zellus*
sp. and an unidentified *Anthocoridae*; a Lepidopteran, *Pyroderces*
sp; and three Hymenopteran parasites of the family *Encyrtidae*,
one an *Anagyrus* sp. An *Ocuptamus* sp. was observed in high popu-
lations but was hyperparasitized.

At both CIAT and in Pernambuco, Brazil, the fungal patho-
gen *Cladosporium* was observed parasitizing *P. herreni* nymphs
and adults. Fungal attacks give mealybugs a sooty, dark grey
to black appearance. A high rate of parasitism was observed
in cassava fields in Pernambuco. Observations indicate that
the fungus may be most effective only under high populations.
However, the fungus can be easily cultured on a medium and of-
fers the possibility of spray applications in fields when mealy-

TABLE 8.   POPULATION OF NATURAL ENEMIES OF THE MEALYBUG
           *PHENACOCCUS HERRENI* IN 13 CIAT CASSAVA FIELDS.

| Natural enemies | % of total enemies | % of field surveyed |
|---|---|---|
| *Ocyptamus* | 68.3 | 84.6 |
| *Stenogaster* | | |
| *Cleothera* sp. | 14.6 | 46.1 |
| *Anagyrus* sp. | 9.2 | 61.5 |
| *Sympherobius* sp. | 4.4 | 38.4 |
| *Chrysopa* sp. | 3.3 | 30.8 |

409

TABLE 9.  PARASITES AND PREDATORS COLLECTED ON HIGH FIELD POPULATIONS OF
         *PHENACOCCUS HERRENI* AT CIAT, PALMIRA

| | D A T E | | | | | |
| | Sept. 2, 1982 | | | Sept. 14, 1982 | | |
| | No.<br>Species | No.<br>Indiv. | % of<br>total | No.<br>Species | No.<br>Indiv. | % |
|---|---|---|---|---|---|---|
| PARASITES | | | | | | |
| Hymenoptera | | | | | | |
|  Acerophaga | 1 | 288 | 86 | 1 | 377 | 92 |
|  Other Hymenoptera | 6** | 19 | | 11** | 32 | .08 |
| | | | | | | |
| PREDATORS | | | | | | |
|  Coleoptera | 7 | 26 | 37 | 5 | 9 | 7 |
|  Neuroptera | 2 | 5 | 7 | 1 | 1 | 1 |
|  Diptera | 2 | 30 | 43 | 1* | 106 | 84 |
|  Lepidoptera | 2 | 9 | 13 | 3 | 8 | 6 |
|  Psocoptera | | | | 1 | 1 | 1 |
|  Hymenoptera | | | | 1 | 1 | 1 |

*   *Kalodiplosis coccidarum*

**  Includes hyperparasites

bug populations are low, thereby preventing populations build-ups. Further research should be directed toward this pathogen.

A problem in this mealybug natural enemy complex is the presence of several hyperparasites (Table 5), which can reduce the populations of the natural enemies. *Ocyptamus* sp. is a frecuent predator of mealybugs and appears to be an efficient one; however, as its populations build-up, there is an increased hyperparasitism. Since *Ocyptamus* is a fairly universal predator, it will be difficult to introduce it into areas where it does not already exist and is already accompanied by its hyperparasites. However, precautions should be taken to avoid the introduction of hyperparasites of other natural enemies of the mealybugs.

DISCUSSION AND CONCLUSIONS

Both the *Mononychellus* mites and the cassava mealybugs have numerous natural enemies that exert pressures on pest populations. There is considerable potential for biological control of these pests; the long growing cycle of the cassava crop and the plant ability to tolerate and recuperate from pest damage enhances the use of natural enemies to reduce pest populations. However, it is our opinion that biological control is part of a pest management system and is not exclusive of it; other important components would be the use of resistant varieties and proper agronomic practices. The former is the topic of an accompanying paper, whereas the latter has not been discussed in detail.

Resistance is related to lower fecundity, non preference, increased pest mortality, and increased development time. The combination of these factors tends to decrease pest populations or delay their build-ups to economic injury levels. Host plant resistance and biological control are complementary systems. The effectiveness of one enhances the effectiveness of the other. The presence of an ample natural enemy complex means that lower levels of resistance are required to reduce pest populations. The effective and longlasting control of mites and mealybugs in the Americas will require the use of varieties that are resistant to pests, or, at least, are not highly susceptible.

In Pernambuco, Brazil, and in the Colombian Llanos where several *P. herreni* outbreaks have been recorded, mites and mealybugs are only part of a pest complex in these areas. Other important pests include thrips (*Frankliniella williamsi*), lacebugs (*Vatiga illudens* and *V. manihotae*), the cassava hornworm (*Erinnyis ello*), and stemborers (*Coelosternus* sp. and *Chilimima clarkei*). A pest management program in these areas must also take these other pests into consideration. This program

411

must begin with a cassava variety that is well adapted to the environmental and edaphic conditions of the ecosystem and contains some level of resistance or tolerance to the pest complex (Lozano and Bellotti, 1980; Lozano *et al*, 1980).

There are numerous agronomic practices that, when properly employed, can reduce the severity, incidence, and dissemination of pests. These include removal of infested plants or plant parts, crop rotation, maintenance of clean fields, burning of plant debris (especially after harvest in infested fields), selection of clean planting material and treatment of such with an adequate pesticide (Lozano and Bellotti, 1980; Bellotti, 1982).

Indications are that the center of origin of *P. herrini* has not been determined; most likely, it lies somewhere in South America. The severe outbreak of *P. herreni* in Pernambuco, Brazil, and the Colombian Llanos indicate that the pest is not native to these areas, but rather, was introduced into them. The determination of the origin of *P. herreni* is important because it could lead to the identification of its most efficient natural enemies. Given the similarities between *P. herreni* and *P. manihoti* in mode of attack, plant damage, and taxonomy, the possibility exists that the two species originate from the same or similar ecosystems and that they may even overlap in their geographic range. The present survey work underway in South America hopefully will determine the origin of these species.

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# THE POTENTIAL OF HOST PLANT RESISTANCE IN CASSAVA FOR
# CONTROL OF MITES AND MEALYBUGS

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INTRODUCTION

Stable host plant resistance offers the most advantageous and practical long-range solution for controlling cassava pests because it is economical, easy to use and compatible with other control measures. To develop a resistant cassava cultivar there needs to exist: (1) genetically conditioned resistance; (2) a reliable evaluation scheme and (3) breeding methods to incorporate this resistance into a commercially acceptable cultivar (Bellotti and Byrne, 1979).

Cassava pests represent a wide range of arthropods; more than 200 species have been recorded. Although many are minor pests, causing little or no economic losses, several must be classified as a major pest. These include mites, mealybugs, thrips, hornworms, whiteflies, and lace bugs (Bellotti and Schoonhoven, 1978). Resistance to cassava pests is not reported extensively in the literature.

Until recent years, most reports dealt only with field observations. However, recent research at CIAT, IITA and several national programs (e.g., Brazil and India) has given considerable emphasis to evaluating germplasm and developing insect resistant hybrids. CIAT is actively seeking resistance to mites (3 species), thrips, whiteflies, mealybugs and lace bugs (Bellotti and Kawano, 1980). Varying degrees of varietal resistance have been found to all these pests (CIAT Ann. Rept. 1974, 1977, 1978, 1979, 1981, Byrne *et al*, 1982, Schoonhoven, 1974).

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Manihot esculenta is a perennial shrub that originated in the Americas; it is composed of cultivated clones that have been selected for desirable characteristics over many years by farmers in each ecosystem, including pests and diseases, yield and quality. In most ecosystems, there exist diverse genotype with varying degrees of susceptibility or resistance to biotic problems. In traditional plantations, yield losses are usually limited by a balance existing between potential biological problems and the host plant. Breeding and agronomy programs should try to maintain this balance, which often requires higher resistance levels for modern cultural practices.

CIAT is constantly collecting these landraces from all areas of North, Central and South America; the present germplasm bank consists of more than 3000 accessions, representing considerable generic variability. New accessions, are evaluated for resistance to pests and pathogens and agronomic adaptation.

Several species of mites and mealybugs can cause serious damage to the cassava crop in the Americas. Mite attacks on the cassava crop are historic (Bondar, 1938), while outbreaks and crop damage due to mealybugs are a recent phenomenon (Albuquerque, 1976). A recent outbreak of the mealybug *Phenacoccus herreni* has caused extensive yield losses in Pernambuco, Brazil (Bellotti, personal observation). This paper will deal with resistance studies for the *Mononychellus* mite complex and the mealybugs *P. herreni* and *P. gossypii*.

THE *MONONYCHELLUS* MITE

More than 40 species of mites are recorded as feeding on cassava; those most frequently reported are *Mononychellus caribbeanae* (McGregor), *M. tanajoa* (Bondar) and two species of the two spotted mite complex, *Tetranychus cinnabarinus* (Boisduval) and *T. urticae* (also reported as *T. bimaculatus* Harvey and *T. telarius* (L.)). Recently *M. tanajoa* was separated into two species; *M. tanajoa* and *M. progresivus* (Doreste, 1981). Mite damage in the Americas is primarily reported from Brazil, Colombia and Venezuela.

CIAT Screening Program for Mite Resistance

CIAT has done extensive screening for mite resistance to three mite species, *Mononychellus* sp. *T. urticae*, *Oligonychus peruvianus* (Bellotti and Guerrero, 1977). Primary emphasis is given to the *Mononychellus* mite. The CIAT screening program for this species consists of three phases.

418

1. Preliminary screening

   a.  Field.- in the germplasm bank with natural infesta-
       tion.

   b.  Greenhouse.- with potted plants and artificial in-
       festation.

2. Replicated evaluation trial at CIAT of selected lines

3. Replicated evaluation trials at other sites (primarily
in northern coastal region of Colombia, i.e., Fonseca and Valle-
dupar).

Greenhouse screening can be useful for four seasons: (1)it
requires less space; (2) it requires less time; (3) it allows
for off season screening and (4) it allows for better control
of screening conditions.  Studies with mite resistance show a
favourable correlation with cassava plant reaction in greenhouse
vs. field resistance (Byrne, 1980).  However, final evaluations
for resistance should be done under high pest populations in
the field, and greenhouse screening is primarily utilized as a
rapid method for eliminating susceptible cultivars.

Varieties selected as resistant are fed into the CIAT germ-
plasm development section where cosses are made between resis-
tant x resistant or resistant x high yielding varieties.  Pro-
geny are reevaluated at the Fonseca or Valledupar sites under
heavy natural mite attack.

A damage scale has been developed on studies of the progres-
sive symptomatology of the *Mononychellus* mite:

1 = None to a few yellow spots on the shoot leaves

2 = Shoot and adjacent leaves with an intermediate number
    of yellow spots.

3 = Shoot and adjacent leaves with many spots.

4 = Shoot and/or adjacent leaves with a slight yellowing,
    many yellow spots.  Slight deformation of the apical
    leaves.  Slight reduction of the shoot.

5 = Shoot intensely deformed and/or reduced apical leaf
    deformation.  Many yellow spots.

6 = Shoots intensely deformed and/or reduced.  A general
    yellow or whitish appearance to the leaves, a mosaic
    like deformation of leaves.

7 = Shoot completely reduced with no leaves. Yellowing and/or defoliation in the middle of the plant.

8 = Shoot dead


To date more than 2000 varieties from the CIAT germplasm bank have been screened for *Mononychellys* mite resistance. Evaluations for resistance have been carried out at CIAT and in the north coast of Colombia, for several years. Data from these evaluations have been combined to select 43 promising cultivars for resistance (Table 1). Using the 1-8 damage scale nearly all of these varieties were evaluated as 4 or lower.


## Effects of Mite Damage on Cassava

Eight varieties, four resistant: (MCol 1434, MVen 125, MCol 282, and M8ra 12), and four susceptible (MCol 22, MCol 1438, Enanita, MCol 113) were compared in protected and unprotected plots during a four month mite attack. In contrast to resistant cultivars, susceptible cultivars as a whole had significant losses in fresh root yield, numbers of roots, total plant weight, harvest index, number of planting stakes produced, leaf size, leaf formation rate, and plant height (Table 2). Without insecticide protection both the resistant and susceptible cultivars lost significantly more foliage than with protection but the susceptible cultivars were relatively more affected than resistant ones. Susceptible cultivars lost more photosynthetic area than resistant ones due to mite attacks, as evidenced by a greater reduction for a longer period in leaf size, leaf area and leaf formation rate (Table 3)(Byrne *et al*, 1982). The reduction of leaf life and leaf size would have a direct effect on the leaf area index (Cock, 1978) which, in turn is associated with root yield potential (Cock, 1979). The marked reduction in these two parameters in susceptible cultivars indicate that these cultivars would suffer greater yield loss than the resistant cultivars. In fact the average yield loss for susceptible cultivars was 73% compared to 15% for resistant cultivars.

Mean mite density (mites/cm$^2$) over a period from the third to the eighth month of plant growth on the four resistant cultivar was 1.0 while on susceptible cultivars it was 3.9 (Fig. 1). Mite damage was correspondingly higher on susceptible than on resistant cultivars (Fig.2).
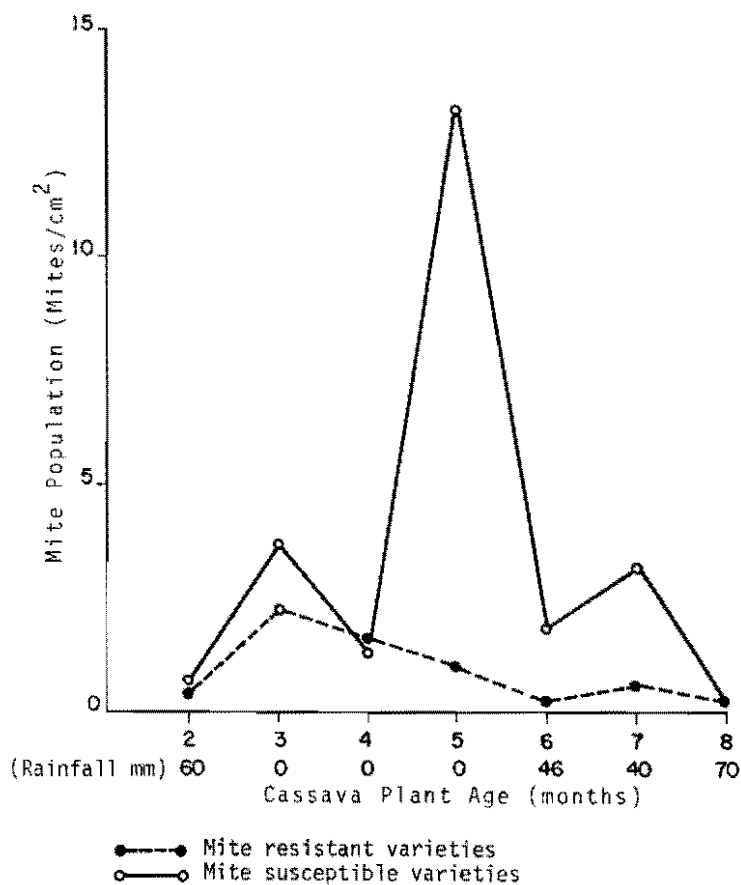
FIGURE 1.   MITE DENSITY (mites/cm$^2$) ON FOUR RESISTANT VS. FOUR SUSCEPTIBLE CASSAVA VARIETIES AT FONSECA, GUAHIRA, COLOMBIA
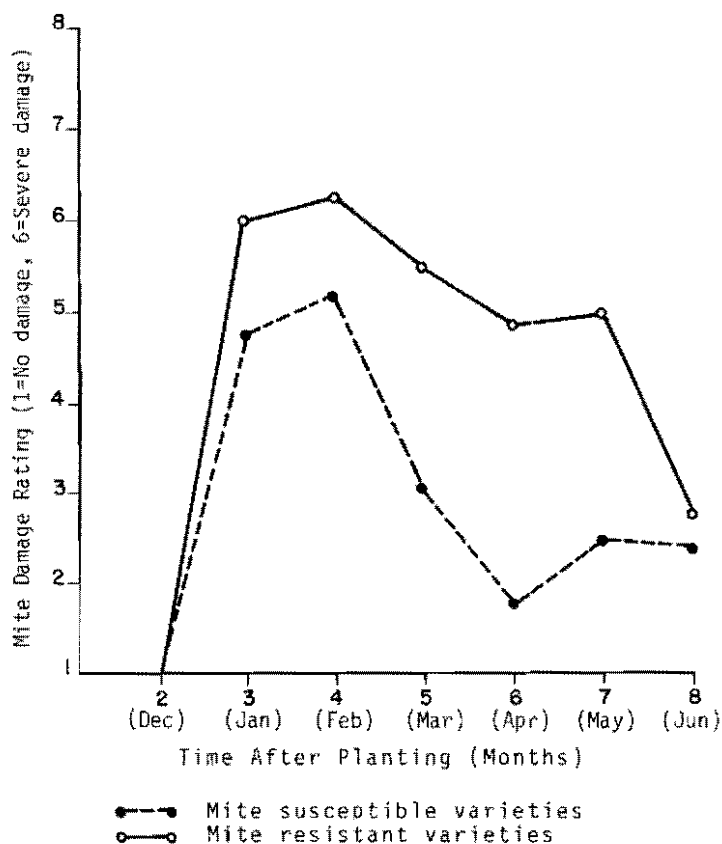
FIGURE 2. FOLIAR MITE DAMAGE (*Mononychellus* sp.)
FLUCTUATION ON MITE RESISTANT AND MITE
SUSCEPTIBLE CASSAVA VARIETIES IN FONSE-
CA, GUAJIRA, COLOMBIA.

## Resistance Mechanisms

The biology of the *Mononychellus* mite has been studied on resistant and susceptible cultivars to determine what factors might be governing resistance.

Rate of mite development was studied on a resistant (MCol 1434) and susceptible (MCol 22) cassava cultivar under laboratory conditions. Female mites consistently developed more slowly (75%) on the resistant cultivar, had a shorter adult life span (45%), a longer pre-ovipositional period (21%) and laid less eggs in their lifetime (59%)(Table 4). Larval and nymphal mortality was greater on the resistant cultivar (Table 5). Additional studies showed that the highest adult female mortality occurs in the first five days of adult life on the resistant cultivar but is delayed until the 8th day for the susceptible one. This early mortality is important because 70-80% of the eggs laid were oviposited in the first 8 days of adult life.

Mite fecundity and ovipositional preference were studied on several resistant and susceptible cultivar in the laboratory. Susceptible cultivars (MCol 22 and MCol 1438) were most prefered, and fecundity was greater than on resistant cultivars (Table 6). Resistant clones MCol 282 and MCol 1434 received only 38 and 34% of the total eggs oviposited on MCol 22.

Greenhouse studies on the growth of mite populations show that populations increase to a greater number on susceptible than on resistant cultivars (Table 7). After a 26-day period the mite population on MCol 22 was 40% higher than on MCol 1434. The number of eggs oviposited was 35% higher on MCol 22.

These results indicate at least two types of mite resistance mechanisms. The slower development of mites, shorter adult lives and higher larval and numphal mortality on resistant cultivars indicate the presence of an antibiosis mechanism. In addition an ovipositional preference mechanism is indicated (Table 6).

## Breeding for Resistance

Heritability studies based on mid-parent-progeny regressions for *Mononychellus* sp. mite resistance indicate primarily additive genetic variability. Estimates obtained for narrow sense heritability at Fonseca (high mite populations) and CIAT, Palmira (moderate mite populations) were 0.94 and 0.78 respectively (Fig.3). This parental selection will be critical to accumulating high levels of resistance in new hybrids. These data also show that selection under high mite pressure should provide better opportunity for effective selection.
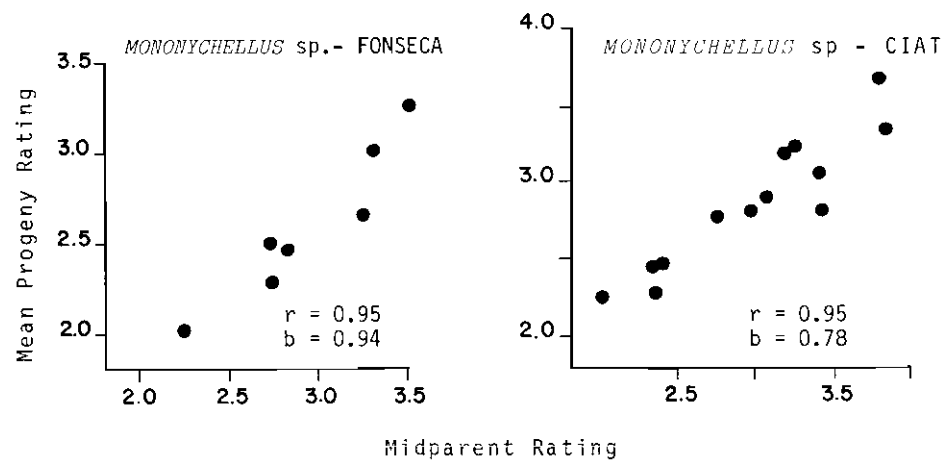
FIGURE 3.   REGRESSIONS OF PROGENY ON MIDPARENT VALUES FOR RESISTANCE
            TO SEVERAL MITE AND INSECT PESTS OF CASSAVA.

Most of the germplasm accessions identified as resistant (Table 1) are agronomically inferior types, consequently, a program is underway to combine resistance with good yield and quality performance. Clones such as MBra 12 which already combine susceptible yield and resistance are used heavily in hybridizations. Many first generation hybrids, now in the second year yield trials are superior to either parent in resistance and yield (Table 8).

THE MEALYBUG (*Phenacoccus herreni and P. gossypii*)

Although mealybugs have previously been reported feeding on cassava (Hambleton, 1935) only in recent years have they been reported as causing serious crop damage in Africa and the Americas. Research centering on host plant resistance to mealybugs has recently been initiated at CIAT. There are no reports in the literature of cassava resistance to mealybugs in the Americas. In fact Albuquerque (1976) reported a severe attack of mealybugs (probably *P. herreni*) causing plant mortality at the Centro de Pesquisa Agropecuaria do Tropico Umido, in Belem, Brazil in 1975; all 150 cassava varieties at the center were susceptible.

CIAT Screening Program for Mealybug Resistance

The 3000 plus accessions in the CIAT germplasm bank are being systematically evaluated for resistance to *P. herreni*. The initial screening phase is undergreenhouse conditions, as a rapid method for discarding susceptible cultivars. Promising clones are later evaluated under field conditions.

A damage scale based on plant reaction under mealybug (*P. herreni*) attack is employed. Two measurements are made, based on level of mealybug infestation (population level) and on damage symptoms.

Infestation Level Scale

    0 = No stages present

    1 = Presence of nymbhs in the growing shoot

    2 = Presence of nymphs and adults  in growing shoots

    3 = Presence of ovisacs and biological stages in growing
        shoot.

4 = Presence of ovisacs and biological stages in growing shoot and middle leaves

5 = Presence of nymphs, adults and ovisacs on all leaves.

Damage Symptoms Scale

0 = No plant damage

1 = Light indulations on the margins of apical leaves

2 = Some curling of the growing shoot

3 = Shoot becomes rosette-like with yellowing of leaf margins

4 = Death of apical leaves and presence of sooty mold.

5 = Death of shoot, defoliation and heavy sooty mold present.

## Resistance to *Phenacoccus herreni*

Four hundred cultivars have been evaluated; results show that a range of population reaction and damage symptoms exist in cassava germplasm. About 3% of the cultivars evaluated displayed light damage symptoms (1-2 on the 0-5 damage scale) although several of these had a high infestation level (Table 9).

The typical damage symptoms (rosetting and downward curling of shoot leaves even under low infestation levels) indicate the presence of an insect toxin. Plants exhibiting high mealybug populations with absence of the rosetting of "cabagge like" effect to the growing shoot may not be susceptible to the toxin being injected by the mealybug. Mealybug populations on these cultivars are less protected and more exposed to the natural enemies, usually found in high numbers in cassava fields.

## Studies with *Phenacoccus gossypii*

The life cycle of *P. gossypii* was studied on five cassava cultivars (MMex 59, MCol 655, MCol 1890, MCol 1185 and MCol 1065). Significant differences between cultivars were found in the average duration of the life cycle and in the duration of each instar (Table 10). The life cycle was shortest on MCol 1185 and MCol 655 and longest on MCol 1065. Significant differences were also found in the size of females during the different instars, with the greatest increase in size during the

last instar (Varela *et al*, 1979). These results indicate that differences in varietal reaction, measured by biological development, exist in cassava germplasm. Further studies, especially with *P. herreni*, are indicated.

CONCLUSIONS

Resistance to mites and mealybugs exists in cassava germplasm; resources in resistance studies is more advanced with mites than with mealybug. Mite resistance is manifiested by slower development of females, a shorter adult life span, reduced oviposition and greater larval and nymphal mortality. These factors make cassava mite resistance idealy compatible with biological control programs. The reduced mite population on resistant cultivars give natural enemies an increased probability of being successful in further reducing mite populations. Some resistance to mites already exists in the landrade cultivars selected over many years by farmers. Breeding programs tha include the use of these resistant cultivars, combining them with high yield potential cultivars stand a good chance of success. Present studies at CIAT show that resistance to mites is highly heritable and that this resistance is probably polygenic; it should therefore be a stable resistance.

Mealybug resistance studies are in the initial stages. Indications are that resistance exists in cassava germplasm. The development of mealybug resistant cultivars will increase the probability of success of biological control programs.

TABLE 1.   FORTY THREE CASSAVA VARIETIES SELECTED AS PROMISING
           FOR RESISTANCE TO THE *Moronychellus* sp. MITE BASED
           ON GREENHOUSE AND FIELD EVALUATIONS.

| Variety | Rating | Evaluation site | Variety | Rating | Evaluation site |
|---------|--------|-----------------|---------|--------|-----------------|
| M Bra 12 | 3.4 | Fonseca | M Col 1602 | 3.0 | CIAT |
| M Col 29 | 2.0 | CIAT | M Col 1962 | 4.0 | Fonseca |
| M Col 132 | 3.5 | Fonseca | M Ecu 85 | 3.3 | Fonseca |
| M Col 1.52 | 3.0 | CIAT | M Ecu 162 | 2.3 | Fonseca |
| M Col 190 | 2.5 | CIAT | M Cr. 3 | 3.3 | Fonseca |
| M Col 191 | 5.0 | Fonseca | M Cr. 6 | 4.4 | Fonseca |
| M Col 247 | 4.3 | Fonseca | M Cr. 10 | 2.0 | Fonseca |
| M Col 255 | 2.5 | CIAT | M Mex 17 | 2.0 | Fonseca |
| M Col 282 | 4.0 | Fonseca | M Mex 20 | 4.4 | Fonseca |
| M Col 310 | 2.8 | Molina | M Mex 25 | 2.8 | Fonseca |
| M Col 319 | 2.7 | Molina | M Mex 27 | 4.0 | Fonseca |
| M Col 323 | 3.0 | CIAT | M Mex 71 | 3.8 | Fonseca |
| M Col 395 | 3.5 | Fonseca | M Pan 70 | 2.5 | CIAT |
| M Col 414 | 2.8 | Fonseca | M Pan 114 | 3.9 | Fonseca |
| M Col 726 | 3.5 | CIAT | M Ven 116 | 2.6 | Fonseca |
| M Col 749 | 3.0 | CIAT | M Ven 121 | 2.8 | Molina |
| M Col 1292 | 3.0 | Fonseca | M Ven 122 | 2.9 | Fonseca |
| M Col 1420 | 3.0 | CIAT | M Ven 125 | 2.1 | Fonseca |
| M Col 1433 | 4.5 | Fonseca | M Ven 126 | 2.8 | Molina |
| M Col 1434 | 4.1 | Fonseca | M Ven 133 | 2.5 | CIAT |
| M Col 1457 | 2.4 | Fonseca | M Ven 214 | 3.0 | CIAT |
| M Col 1524 | 3.0 | CIAT | | | |

1   Damage scale of 1-8, where

    1 = very low damage
    8 = very high damage (see text).

428

TABLE 2. THE EFFECT OF A MITE (*Mononychellus* sp) ATTACK ON
DIFFERENT PARAMETERS OF RESISTANT VARIETIES AT FON-
SECA, COLOMBIA (OCTOBER 1978 - JUNE 1979)

| Parameter | Change 14 parameter com- pared to protected plots (%) | |
|---|---|---|
| | Resistant | Susceptible |
| Yield (kg fresh root weight) | -17.9 ns[2] | -69.4*[2] |
| Number of roots per plot | -11.9 ns | -43.0* |
| Weight per root (kg/root) | - 9.6 ms | -43.7* |
| Weight commercial roots to total root weight | - 5.7 ns | -45.0* |
| Branch weight (kg/plot) | + 0.4 ns | -47.4* |
| Total weight (kg/plot) | - 7.8 ns | -60.9* |
| Harvest index | -11.1 ns | -26.3* |
| Planting stakes obtaineable | -19.1* | -67.3* |
| Leaf size ($cm^2$/leaf) | - 4.9 ns | -34.3* |
| Leaf formation rate (leaves/day) | 0.0 ns | -13.3* |
| Foliage (cm shoot with foliage | -27.3* | -42.1* |
| Refoliation (%) | +18.5* | +23.8* |
| Plant height (cm) | - 7.7* | -21.7* |

1    1- (unprotected plot/protected plot)
2    ns = not significant
     *  = significant at a 0.05 level
     (Byrne, 1980).

TABLE 3. THE EFFECT OF *~~~~~~~~~* MITE ATTACK ON LEAF SIZE, LEAF LIFE AND LEAF FORMATION RATE IN PROTECTED PLOTS COMPARING RESISTANT AND SUSCEPTIBLE CULTIVARS.

| | | | | C U L T I V A R S | | | | |
| Treatment | MCol 22 | MCol 1438 | Enanita | MCol 113 | MCol 1434 | MVen 125 | MCol 282 | MBra 12 |
|---|---|---|---|---|---|---|---|---|
| **CULTIVAR MEAN-LEAF SIZE ($cm^2$)** | | | | | | | | |
| Protected | 114b* | 65d | 150a | 116b | 119b | 127b | 126b | 117b |
| Non protected | 64d | 43c | 97c | 86c | 118b | 119b | 116b | 120b |
| **CULTIVAR MEAN-LEAF LIFE (WEEKS)** | | | | | | | | |
| Protected | 14.6ab | 12.1cd | 16.2a | 14.1b | 13.2bc | 16.3a | 13.7bc | 13.0bc |
| Non protected | 5.8h | 5.7h | 6.7gh | 6dh | 8.7f | 8 2fg | 9.9ef | 10.6de |
| **CULTIVAR MEAN-LEAF FORMATION RATE (LEAVES/WEEK)** | | | | | | | | |
| Protected | 0.43b | 0.39bc | 0.50a | 0.50a | 0.54a | 0 52a | 0.50a | 0.49a |
| Non protected | 0.34c | 0.35c | 0.39bc | 0.50a | 0.53a | 0.50a | 0.52a | 0.50a |

* Means with same letter are not significantly different using Duncan's multiple range test at the same probability level. (Byrne, 1980).

TABLE 4.    RATE OF MITE (*M. tanajoa*) DEVELOPMENT ON TWO
            CASSAVA VARIETIES IN THE LABORATORY (DAY 30°C,
            NIGHT 28°C, 12 HOUR DAY, 40-70% RH).

| Developmental stage[1] or measure[2] | MCol 22 | MCol 1434 |
|---|---|---|
| Egg | 4.09 | 4.34 *** |
| Larvae | 1.16 | 1.36 *** |
| Protocrysalis | 0.76 | 0.80 ns |
| Protonymph | 0.61 | 0.93 *** |
| Deutocrysalis | 0.70 | 0.73 ns |
| Deutonymph | 1.03 | 1.23 ** |
| Teliocrysalis | 0.86 | 0.83 ns |
| Preovipositional period | 1.21 | 1.52 * |
| Egg to adult: | | |
|   Female | 9.18 | 9.92 ** |
|   Male | 8.58 | 10.13 ns |
| Egg to egg | 10.39 | 11.37 ** |
| Adult life span | 7.64 | 4.22 ** |
| | 4.63 | 4.28 ns |
| Lifetime fecundity | 12.33 | 5.05 ** |

1    Stage duration in days

2    Fecundity a number of eggs per female

3    Significance of test:
   ns = not significant
    *   = 5% level
   ++ = 1% level
  *** = 0.1% level
(Byrne, 1980)

431

TABLE 5.  LARVAL AND NYMPHAL MITE (*Mononychellus tanajoa*)
          MORTALITY ON A RESISTANT AND SUSCEPTIBLE CASSSA-
          VA VARIETY IN TWO LABORATORY EXPERIMENTS.

| Stage of mortality | Percent mortality | | | |
|---|---|---|---|---|
| | First experiment | | Second experiment | |
| | MCol 22 | MCol 1434 | MCol 22 | MCol 1434 |
| Larvae | 26.7 | 52.2 | 14.9 | 17.4 |
| Protonymph | 12.8 | 10.0 | 10.0 | 22.1 |
| Deutonymph | 15.1 | 12.2 | 10.0 | 12.6 |
| Total | 54.6 | 74.4* | 34.0 | 52.1** |

*   Significantly different at 5% level

**   Significantly different at 10% level

    (Byrne, 1980).

TABLE 6. MITE (*M. tanajoa*) FECUNDITY AND OVIPOSITION PREFER-
ENCE (LEAF DISKS IN GROWTH CHAMBER) ON SEVEN CASSA-
VA VARIETIES COMPARED TO FIELD DAMAGE RATING

| Variety | Fecundity (egg/2 days) | Preference (% of most pref.) | | Damage[1] rating |
|---------|------------------------|------------------------------|---|------------------|
| MCol 22 | 6.77 A$^2$ | 100$^3$ A | | S |
| MCol 1438 | 6.05 A | 98 A | | S |
| MBra 12 | 5.95 A | 73 B | | R |
| MVen 125 | 4.73 B | 47 C | | R |
| MCol 113 | 4.67 B | | | I |
| MCol 282 | 4.42 B | 38 CD | | R |
| MCol 1434 | 3.25 C | 36 C | | R |

1 = R: Resistant
    I: Intermediate
    S: Susceptible

2 = Duncan's multiple rage test, means with the same letter
    are not signifficantly different at the 5% level

3 = Analysis done on two day mite counts for dates from all
    combinations of the varieties.

TABLE 7.   GROWTH OF A MITE (*Mononychellus tanajoa*) POPULATION ON FOUR CASSAVA VARIETIES IN THE GREENHOUSE IN 26 DAYS

| Variety | No. mite/plant after 26 days | Number mites | | Resistance rating[2] | No. eggs plant | No. eggs per initial female |
| | | per female | % of susceptible | | | |
|---|---|---|---|---|---|---|
| MCol 22   (S) | 2,299 A[1] | 148 | 100 | 3.64 | 4,485 a | 299 |
| MBra 12   (R) | 1,478 B | 99 | 66 | 2.28 | 3,165 b | 211 |
| MCol 113  (I) | 1,469 B | 98 | 66 | 2.73 | 2,385 b | 159 |
| MCol 1434 (R) | 1,337 B | 89 | 60 | 2.14 | 2,940 b | 196 |

1    Duncan's multiple range test at 5% level.  Means with the same letter are not significantly different.

2    1 = very resistant - shoot on adjacent levels with a few faint yellowish spots.
     5 = very susceptible - shoot dies, plant does not develope
     (Byrnem 1980).

TABLE 8.  SELECTIONS FOR MITE RESISTANCE AND YIELD POTENTIAL
          IN VALLEDUPAR AND CIAT PALMIRA

| Hybrid | Parents | | | Resistance of hybrids | parents | | |
|--------|---------|---|---|---------|---------|---|---|
| CG 1-7 | MBra 12 | x | MCol 22 | MR | R | x | S |
| 1-32 | MBra 12 | x | MCol 22 | MR | R | x | S |
| 1-56 | MBra 12 | x | MCol 22 | R | R | x | S |
| 1-57 | MBra 12 | x | MCol 22 | R | R | x | S |
| 4-81 | MCol 22 | x | MCol 282 | R | S | x | R |
| 5-55 | MCol 22 | x | MCol 414 | R | S | x | R |
| 5-78 | MCol 22 | x | MCol 414 | R | S | x | R |
| 5-79 | MCol 22 | x | MCol 414 | R | S | x | R |
| 5-99 | MCol 22 | x | MCol 414 | R | S | x | R |
| 7-30 | MCol 113 | x | MCol 22 | MR | MR | x | S |
| 7-56 | MCol 113 | x | MCol 22 | R | MR | x | S |
| 22-2 | MMex 1 | x | MCol 1684 | R | MR | x | S |

TABLE 9.   SELECTED VARIETIES FROM AN EVALUATION OF 400
CASSAVA VARIETIES FOR RESISTANCE TO *Phenaco-*
*ccus herreni* under greenhouse conditions (AV-
ERAGE TEMPERATURE 24°C AND 70% RH).

| Variety | Infestation[1] level | Damage[2] level |
|---------|---------------------|-----------------|
| MCol 2 | 5 | 2 |
| MCol 181 | 4 | 2 |
| MCol 214 | 4 | 2 |
| MCol 233 | 5 | 2 |
| MCol 253 | 3 | 2 |
| MCol 263 | 5 | 1 |
| MCol 270 | 5 | 2 |
| MCol 279 | 5 | 2 |
| MCol 286 | 5 | 2 |
| MCol 296 | 3 | 2 |
| MCol 299 | 4 | 2 |
| MCol 310 | 5 | 2 |

1    Infestation level: 0 = no infestation
                        3 = moderate infestation
                        5 = heavy infestation
2    Damage level: 0 = no damage
                   3 = moderate damage
                   5 = severe damage

TABLE 10.   RATE OF *Phenacoccus gossypii* DEVELOPMENT ON FIVE
            CASSAVA VARIETIES UNDER FIELD CONDITIONS (TEMP.
            23.5°C AND 72% RH).

| Variety | No. of observ. | Means duration of instars (days) | | | | Mean total duration |
| | | 1st | 2nd | 3rd | 4th | |
|---|---|---|---|---|---|---|
| MMex 59 | 42 | 9.9 | 6.2 | 7.0 | 6.8 | 29.6a* |
| MCol 655 | 15 | 9.2 | 5.7 | 5.5 | 8.2 | 30.2ab |
| MCol 1890 | 45 | 11.0 | 6.0 | 6.0 | 8.2 | 31.0b |
| MCol 1185 | 40 | 8.0 | 8.0 | 7.0 | 7.0 | 29.7a |
| MCol 1065 | 35 | 10.0 | 9.0 | 7.0 | 6.0 | 32.1c |

\*   Mean values followed by the same letter are not signifi-
    cantly different using Duncan's multiple range test at
    the same probability level.

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438

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# RECENT ADVANCES IN RESISTANCE TO INSECT AND MITE PESTS

## OF CASSAVA (*Manihot esculenta* Crantz)

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INTRODUCTION

Cassava (*Manihot esculenta*) is a perennial shrub of the Euphorbiaceae. It is grown throughout the tropical regions of the world and is a major energy source for 300 to 500 million people. Cassava originated in the Americas, was later taken to Africa, and more recently introduced into Asia (Leon, 1977, Beck, 1982). Cassava is cultivated mainly in developing countries on small farms with little modern technology. Depending on ecological conditions, the growing period is 8 to 24 months.

Cassava pests represent a wide range of arthropods; approximately 200 species have been recorded. Although many are minor pests, causing little or no economic losses, several must be classified as major pests. These include mites, thrips, mealybugs and whiteflies. This complex has been extensively reviewed by Bellotti and Schoonhoven (1978).

Since cassava is a long season crop, often grown by subsistance farmers with a low profit margin, the continual use of pesticides to control insects and mites is economically prohibitive as well as environmentally unsound. The most feasible alternatives methods of control are host plant resistance, biological control, and cultural practices, or any combination of these (Bellotti and Kawano, 1980).

Resistance to insects or mites attacking cassava is not extensively reported in the literature, many of the reports deal only with field observations and until recently, there was little systematic evaluation of germplasm. Because of recent interest in cassava several national and international institutions have assembled extensive germplasm banks which are available to

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researchers for evaluation for resistance to the numerous cassava pests (Byrne, 1984).

At present, cassava is grown mostly on small plots by small farmers throughout the tropical growing regions of the world. The genetic variability in this system is enormous, because each area or zone often is sown to a distinct variety. The genetic variability in this system constitutes, in essence, a geographic multiline which is a genetic safeguard against major epidemics of pests and diseases. This is especially true in the Americas where cassava has evolved and been cultivated for thousands of years, resulting in thousands of traditionally grown varieties. The CIAT germplasm bank, a collection of farmer grown varieties now exceeds 3800 accessions. Many of these accessions contain resistance to one or more of the major cassava pests (Byrne, 1984; CIAT, 1975, 1976, 1977, 1978, 1979, 1980a, 1981, 1982, 1983, 1984)

In contrast, cassava growing regions of Africa and Asia do not contain this extensive genetic diversity. In Africa, in recent years, this lack of genetic diversity has contributed to the widespread outbreaks of mites and mealybugs causing severe crop losses (Herren, 1981). These types of pest outbrakes have rarely occured in the Americas. In Asia, where genetic uniformity is more common, such as in Thailand (Cock, 1985), there exists the potential danger for severe, widespread pest outbreaks.

As new, high-yielding hybrids are developed, released, and sown to extensive areas, genetic uniformity will increase and much genetic variability may eventually disappear. The new hybrids will be well suited to modern agronomic practices, but such genetic uniformity is an invitation to disaster from epidemics of pests and diseases. In subsistence agriculture, in which much of cassava is now grown, there is a reasonable stable equilibrium between pests and genotypes. Integrated control program built around plant resistance are needed to maintain this equilibrium in modern agricultural systems, where extensive areas are planted to uniform genetic material (Bellotti and Kawano, 1980).

IMPORTANCE OF RESISTANCE IN CASSAVA PEST MANAGEMENT

Resistance of plants to insects is the property that enables a plant to avoid, tolerate, or recover from injury by insect and mite populations that would cause greater damage to other plants of the same species under similar environmental conditions. This property usually derives from certain biochemical and/or morphological characteristics of plants wnich so effect the behavior and/or the metabolism of insects or mites as to influence the re-

442

lative degree of damage caused by these pests (Kogan, 1975).

Stable host plant resistance offers the most advantageous and practical long-term solution for controlling cassava pests because it is economical, easy to use and compatible with other control measures (Bellotti and Byrne, 1979). Kogan (1975) describes other desirable features of host plant resistances:

1. Specificity.- plant resistance is usually specific to a pest or pest complex with no direct detrimental effect on beneficial insects.

2. Cumulative effect.- immunity to the insect or mite is not needed because the effect on the pest population may be compounded in succeeding generations.

3. Persistence.- most resistant varieties remain stable for a long time.

4. Harmony with the environment.- there is virtually no danger of contaminating the environment or endangering man or wild life.

The compatibility of plant resistance with other tactics in pest management make it especially attractive to the cassava agroecosystem. Cassava, being a long season, vegetatively propagated, crop, it is often subjected to continual attacks of insects, mites and diseases. This cassava pest complex is in turn, attacked by numerous natural enemies, including parasites, predators and microorganisms, that help reduce and stabilize the pest population. Plant resistance and this biological control are compatible and complimentary systems.

Normally, selected clones should have a balanced resistance to all the important problems in a given ecosystem. Selection for single resistance factors without considering other traits or pests and diseases may be a useful tool in specific pathological or entomological studies, but generally it is an inefficient means to accumulate resistance factors to a complex of diseases and pests (Lozano *et al*, 1983).

THE CASSAVA INSECT AND MITE COMPLEX

Most Important Species and its Geographic Distribution

There are 17 major pests of cassava (Bellotti and Schoonhoven, 1978). The general groups of pests described in Table 1 are all found in the Americas, 12 are reported from Africa and 6 are found in Asia (Bellotti and Schoonhoven, 1977). This is expected since, wherever there is great variations of the host

TABLE 1. CASSAVA PESTS AND THEIR CONTROL

| Common name | Scientific name | Control |
|---|---|---|
| Mites | *Mononychellus* spp.<br>*Tetranychus* spp.<br>*Oligonychus* spp. | R, BC, C |
| Thrips | *Frankliniella williamsi*<br>*Corynothips stenopterus*<br>*Caliothrips masculinus* | R, C |
| Lace bugs | *Vatiga manihotae*<br>*Vatiga illudens* | R |
| Whiteflies | *Aleurotrachelus socialis*<br>*Bemesia tabaci*<br>*Aleurothrixus aepim* | R, C |
| Mealybugs | *Phenacoccus herreni*<br>*Phenacoccus manihoti* | R, BC, CP |
| Hornworm | *Erinnyis ello*<br>*Erinnyis alope* | BC, C |
| Scales | *Aonidomytilus albus*<br>*Saissetia* spp | BC, CP, C |
| Subterranean sucking | *Cyrtomenus bergi* | CP, R |
| Shoot flies | *Silba pendula*<br>*Neosilva perezi*<br>*Carpolonchaea chalybea* | CP, C |
| Stemborers | *Coelosternus* spp.<br>*Chilomina clarkei*<br>*Lagocheirus araeniformis* | CP, C |
| Fruit flies | *Anastrepha* spp. | C |
| Termites | *Coptotermes* spp. and others | C |
| Leaf-cutting ants | *Atta* spp. | C |
| Gall midges | *Jatrophobia brasiliensis* | C, BC |
| Verigated grasshoper | *Zonocerus* spp. | C, R |
| Leaf beetles | *Colapsis* sp. and others | C |
| Cutworms | *Prodenia eridania*<br>*Agrotis ipsilon* | C |

R = Resistance
BC = Biological control
C = Chemical control

**444**

plant, there is a great variability in the organisms that attack the plant or are in symbiotic relationship with it (Jennings and Cock, 1977).

Yield Losses and Type of Damage

Cassava is often considered a rustic crop and therefore generally free of arthropod pests. Studies now show that cassava is not free from insect and mite attacks, and that these pests are limiting factors in production.

Insects can damage the plant by attacking the leaves, reducing photosynthetic area and efficiency; by attacking the stems, weakening the plant, and inhibiting nutrient transport; and by attacking planting material, leading to microbial invasion that reduces germination and yield. Some pests, such as whiteflies and fruit flies, are vectors or disseminators of diseases; others attack the roots, leading to secondary rots.

Indications are that pests that attack the plant over a prolonged period, such as mites, thrips, lace bugs, mealybugs, whiteflies, and stem-borers, reduce yield more than those that defoliate or damage plant parts for a brief period, that is hornworms, fruit flies, shoot flies, and leaf-cutter ants. The cassava plant recuperates from this type of damage under favorable environmental conditions. Adequate rainfall and soil fertility are the critical factors. Cassava is often grown in regions with prolonged dry seasons because it tolerates water stress. However, populations of thrips, mites, lace bugs, and mealybugs increase during dry periods and compound the damage to the crop.

Yield losses have been recorded for several cassava pests. These include mites (8 to 87%), whiteflies (4 to 79%, depending on length of attack), mealybugs (up to 88% on susceptible cultivars), thrips (6 to 28% depending on varietal susceptibility), hornworm (18%, single attack), scales (4 to 19%), and stemborers (up to 56% when heavy stem breakage occurs) (Bellotti *et al*, 1983).

PRIORITIES IN A CASSAVA PEST RESISTANCE PROGRAM

The cassava pest complex represents a wide range of athropod fauna (Bellotti and Schoonhoven, 1978). It is unrealistic to consider breeding for resistance to all these pests, nor is it necessary to do so as there are alternative methods for controlling many pests. Cassava pests may be divided into several categories (Table 2):

TABLE 2.   CASSAVA PESTS IN RELATION TO THEIR IMPORTANCE IN A PEST MANAGEMENT
          PROGRAM

| Pest category | Common name | Principal species | Area of importance |
|---|---|---|---|
| Key pests[1] | Mites | *Mononychellus* spp. *Tetranychus* | Americas, Africa Asia |
| | Mealybugs | *Phenacoccus manih ti* *P. herreni* | Africa Americas |
| | Thrips | *Frankliniella williamsi* | Americas |
| Occasional[2] pests | Hornworm | *Erinnyis ello* | Americas |
| | Lace bugs | *Vatiga* spp. | Americas |
| | Whiteflies | *Aleurotrachelus socialss* | Americas |
| | Grasshoppers | *Zonocerus* spp. | Africa |
| | Leaf cutter ants | *Atta* spp. | Americas |
| | Subterranean suck- ing insects | *Cyrtomenus bergi* | Americas |
| Incidental[3] pests | Scales | *Aonidomytilus albus* *Saissetia* spp | Universal |
| | Shoot flies | *Neosilba perezi* | Americas |
| | Fruit flies | *Anastrepha* spp. | Americas |
| | Stemborers | *Coelosternus* spp. *Chilomina clarkei* *Lagochirus* spp. | Americas |
| | Gall midges | *Iatrophobia brasiliensis* | Americas |

1    Pests that regularly limit crop production.
2    Pests that occur at infrequent intervals but causes severe damage when present.
3    Pests that are constantly present but infrequently damaging.

## Key pests

One that regularly limits crop reduction (Ortman and Peters, 1980). These include mites, mealybugs and thrips.

## Occasional pests

Those that occur at infrequent intervals but causes severe damage when present. These include hornwors, lace bugs, whiteflies, grassphoppers and leaf-cutting ants.

## Incidental pests

Is one that is constantly present but infrequently damaging, such as scales, shoot flies, fruit flies, stemborers and gall midges.

## Potential pests

Is one that might occur with a change in crop and cultural practices or one that is introduced into region where it does not presently exist. Several of the above mentioned pests would fall into this group if they were to be introduced from the Americas into Africa or Asia. The mite and mealybug problems in Africa is a good sample of this.

Obviously those considered key pest should be candidates for a host plant resistant program; in fact more emphasis for resistance has been given to mites, mealybugs and thrips than any of the other cassava pests (Byrne, 1984; Bellotti and Kawano, 1980). An additional criteria that is used includes those pests that can attack the crop over a prolonged period of time. The cassava lace bugs and whiteflies as well as the three previous pests are included in this group.

Other criteria that should be considered pertinent in establishing a program that will utilize host plant resistance for specific cassava pests includes (Bellotti and Kawano, 1980):

1. The level of economic damage being caused by a particular pest should be significant.

2. Resistance should be sought for those pests for which it is considered feasible to find resistance. It would be unlikely to find resistance to such pests as the cassava hornworm, cutworms, leaf-cutter ants, or grasshoppers; limited resources should not be used in this direction.

3. The availability of adequate and low-cost alternative methods could negate the need to enter into an extensive re-

447

sistance breeding program. Biological control, cultural practices or even an occasional pesticide application often will maintain pest populations below economic injury level.

4. Low levels of resistance can be adequate if it is combined with other control methods, such as biological control or cultural practices. Under traditional cassava farming conditions, pest populations are maintained at reduced levels by a combination of resistance, natural enemies and improved agronomic practices (Lozano and Bellotti, 1980).

## ADVANCES IN BREEDING FOR INSECT AND MITE RESISTANCE IN CASSAVA

Resistance in cassava has been reported for mites (several species), thrips, mealybugs, whiteflies, scales, stemborers, shootflies, lace bugs and the subterranean sucking insect. Only those considered to be most important in terms of breeding for resistance will be discussed in detail. These include mites, thrips, mealybugs, whiteflies and lace bugs. Resistance studies can generally be divided into two groups:

1. Evaluation of existing germplasm for cultivars expressing resistance to one or more pests.

2. The incorporation of resistant germplasm into a breeding program to produce hybrids expressing resistance to pests and containing acceptable agronomic qualities.

Examples of the former are quite common in national and international cassava improvement programs while examples of the latter are restricted to a limited number of institutions. To develop a resistant cassava cultivar, the following are required:

1. Genetically conditioned resistance

2. A reliable evaluation scheme, and

3. Breeding methods to incorporate this resistance into a commercially acceptable cultivar (Bellotti and Bryne, 1979).

Resistance is partitioned into three components: antibiosis, antixenosis (nonpreference) and tolerance. Antibiosis is when the resistant plant has a detrimental effect on the pest's developmental biology, whereas antixenosis denotes an adverse effect of the plant on the pests behaviour; the plant is avoided by the pest. Tolerance has no effect on the pest population but is rather the plant's ability to wisthstand and/or compensate for the damage caused by the pest. Measures of resistance

448

are variable and relative to other varieties.

Attempts have been made to review the results of cassava insect and mite resistance studies (Byrne, 1984; Bryne *et al*, 1983; and Bellotti and Kawano, 1980). This paper will not attempt to detail all of the past results of cassava pest resistance studies. Only the most recent studies will be examined.

## Mites

Cassava has been screened for mite resistance in numerous countries in the Americas, Africa and Asia and by numerous workers (Byrne *et al*, 1983). Most screening has involved species of the genera *Mononychellus*, *Tetranychus* and *Oligonychus*. Although many of these evaluations were minimally replicated (over one site or in one year), it is evident that all cassava varieties are attacked by mites (i.e. no immunity exists) and that genetically conditioned resistance exists. Most of the recent work with mite resistance deals with *Mononychellus* mite (Table 3), which recently was introduced into Africa from South America. Losses in root yield have varied from 8% to 87% depending on the intensity, length and timing of the attack, as well as the cultivar (Byrne *et al*, 1982a). High levels of resistance have been found for *Mononychellus* mites, possibly because these mites have few alternate hosts and the pest and cultigen have coevolved.

At present, resistance research with the *Mononychellus* mites are primarily confined to three institutions, CIAT in Colombia, IITA in Nigeria and CNMPMF/EMBRAPA in Brazil. All three institutions have screened large amounts of germplasm and have identified mite resistant cultivars (Table 3).

*Mononychellus* mite resistance appears to be based on four different mechanisms of resistance: two mechanisms that alter mite biology, one that involves tolerance, and one associated with pubescence (Byrne *et al*, 1982b). Mites feeding on different varieties were shown to differ significantly in fecundity, acceptance, developmental time, adult life span, larval and nymphal mortality and reproduction in the glasshouse. Mites on susceptible varieties (higher field population and foliar damage ratings) had greater fecundity, greater acceptability, shorter developmental time, longer adult life span, lower adult and nymphal mortality and greater glasshouse reproduction than did mites on most of the resistant varieties (low field populations and foliar damage ratings). There were two distinct patterns of mite reaction on different mite resistant sources; first, that of MCol 1434, which resulted in negative effects on mite fecundity, acceptance, adult female life span, development time, larval and nymphal survival and glasshouse reproduction. The second pattern was exhibit by the clone MBra 12, which is characterized by intermediate acceptance, suppressed adult female

449

TABLE 3. STATUS OF RESISTANCE IN CASSAVA TO THE *Mononychellus* and *Tetranychus* mytes

| Mite species | Institution (country) | Accessions[1] evaluated | Present status | Resistance mechanisms | References |
|---|---|---|---|---|---|
| *M. tanajoa* | CNPMF/Brazil | 357 (F) | 16 resistant | Unknown | Farias *et al* 1981 |
| *M. caribbeanae* | Univ. Puerto Rico | 11 (F) | 3 po-sible resistant | Unknown | Cruz, 1981 |
| *M. progresivus* | IITA, Nigeria | 200,000 seedlings | No selection indicated | | IITA, 1980 |
| | IITA, Nigeria | 60 clones (F) | 10 resistant | Pubescense | Hahn, 1982a |
| *M. tanajoa* | Zaire | 23,936 seeds (IITA) (F) | No selection indicated | | Lutaladio, 1982 |
| | Zaire | 1460 lines (F) | 219 lines selected | | Lutaladio, 1982 |
| *M. progresivus/ M. tanajoa* | CIAT, Colombia | 2197 (G & F) | 43 resistant | Antibiosis Ovopositional | CIAT 1976-84 Bellotti & Byr-ne, 1979 |
| *M. caribbeanae* | | | Mite resistent Hybrids available | Preference | Byrne *et al* 1982a & 1982b |
| *T. kanzawai* | Visayas State Col-lege of Agriculture | 295 (G) | 60 selected | Tolerance | Bernardo & Es-guerra, 1981 |
| | Philippines | 50 (F) | 4 selected | Unknown | Bernardo & Es-guerra, 1981 |
| *Tetranychus* spp. | CTCRI, India | 12 (F) | 5/low mite population | Unknown | Lal & Hrishi, 1981 |
| *T. urticae* | CIAT, Colombia | 2120 (S) | 17 selected as resis-tant | Ovipositional Preference Antibiosis | CIAT, 1978 1979, 1980 |

1  F = Field evaluation
   G = Greenhouse evaluation
   S = Screenhouse evaluation

lifespan and a lowered glasshouse reproduction. When compared
to the susceptible clones, MBra 12 had no effect on mite fe-
cundity, developmental time or larval and nymphal mortality.
Since MCol 1434 and MBra 12 are similar with respect to field
populations, foliar damage ratings and mite reproduction in the
glasshouse, it is suggested that two independent mechanisms e-
xists, but the basis for these has not been clarified (Byrne *et
al* 1982b).

The association of leaf and shoot pubescence and mite re-
sistance has been reported by several workers (Byrne *et al* 1982b;
Hahn, 1982a; CIAT, 1981; IITA, 1981; IITA, 1982). Pubescence
most likely works as a protective barrier for the young shoot
and expanding leaves where the *Mononychellus* mites prefer to
feed. A distance between the trichoms of 0.3 mm or less makes
it difficult for the mites to rest and feed (IITA, 1981). Pu-
bescence, therefore, acts to protect the most susceptible part
of the plant from the *Mononychellus* mite. It is easy to visual-
ly select highly pubescent types and it would be difficult for
the mites to genetically overcome this barrier. However, the
wisdom of selecting for high pubescence as the major factor for
mite resistance is questioned by Ayanru and Sharma (1982) since
a highly pubescent variety TMS/U 42046, showed considerable
chlorophyll depletion when attacked by mites which they linked
to mite susceptibility. This mechanism may be effective at
light or even moderate mite attacks, but appears to be overcome
at very high mite levels.

It is therefore suggested that the goal of a resistance
breeding program should be to combine the several mechanisms in-
volved to insure a resistance that will withstand high mite po-
pulations as well as genetic changes of the mite. This may be
difficult to accomplish since some of the mechanism are not read-
ily identifiable, and therefore not satisfactory for rapid field
screening. More studies into the mechanisms of resistance to
mites are needed to develop better screening techniques. Resis-
tance to the *Mononychellus* mite in cassava appears to be control-
led primarily in the additive mode as shown by the high heritab-
ility estimates (50-78%) (Byrne *et al* 1982a; CIAT, 1981; IITA,
1981).

Most of the germplasm accessions identified as resistant
are agronomically inferior types. Consequently, a program is
underway to combine resistance with good yield and quality per-
formance. Clones such as MBra 12 which already combine suscept-
ible yield and resistance are used heavily in hybridizations.
Many first generation hybrids, now in the third year yield trials
are superior to either parent in resistance and yield.

Resistance studies for the *Tetranychus* mites are not as ad-
vanced as those for the *Mononychellus* mites. At present research
into cassava resistance for the *Tetranychus* mite is mainly being

451

carried out by VISCA in the Philippines, CTCRI in India, and CIAT in Colombia (Table 3). At CIAT 2120 accessions from the germplasm bank were repeatedly evaluated in the screenhouses for resistance to *T.urticae* and 17 cultivars were eventually selected as resistant (CIAT, 1978). These selected cultivars lack a field screening under heavy mite attack to verify screenhouse results. It should be noted that these 17 cultivars are also resistant to the *Mononychellus* mite. Evaluations of 295 cassava accessions at the Visaya's State College of Agriculture in the Philippines resulted in four cultivars eventually being selected as resistant to *T. kanzawai* (Bernardo and Esguerra, 1981a).

The first workers to study the biological response of *Tetranychus* mites to different varieties of cassava found that different occurred in developmental time, adult longevity and mite fecundity (Saradamma and Das, 1974). However this work was not followed up with field studies to confirm whether these differences were responsible for differences in field populations or damage. At CIAT biological studies of *T. urticae* on three cassava cultivars showed that developmental time was greater and female adult longevity was shorter on the resistant cultivars as compared to the susceptible control (CIAT, 1980).

Screening for resistance to *Oligonychus peruvianus* was done in Colombia (CIAT, 1978, 1979), to *O. gossypii* in Nigeria (IITA, 1979), to *O. biharensis* in India (Lal and Hrishi, 1981). At CIAT 250 accessions of 2231 screened were selected as promising for resistance.

Thrips

Several species of thrips are pests of cassava, specially in the Americas (Bellotti and Schoonhoven, 1978). *Franklimilia williamsi* has received the most attention for resistance breeding. This species damages the terminal bud of the plant, leaves do not develop normally, leaflets are deformed and show irregular chlorotic spots. Yield losses range from 6 to 28 percent depending on varietal susceptibility (Schoonhoven and Pena, 1976; CIAT, 1976). Field screening at CIAT showed 20% of the germplasm collection to be highly resistant and an additional 29% show only minor damage (Bellotti and Kawano, 1980). Resistance is related to the pubescence of leaf buds and unexpanded leaves (Schoonhoven, 1974). This gross morphological character for resistance appears to be very stable and biotypes are not expected to develop. The heritibility (narrow and broadsense) of thrips resistance is about 80%, which indicates that it is for the most part additively inherited (Byrne, 1984). Incorporating high thrips resistance into high yielding genotypes, especially for the lowland tropics with a prolonged dry season, is a major component in the CIAT hybridization program. Rapid progress has been made in doing this.

452

## Mealybugs

There are two major species of mealybug attacking cassava in Africa and the Americas. *Phenacoccus manihoti* was introduced from the Americas into Zaire, Africa during the early 1970's (Hahn and Williams, 1973). It has subsequently spread throughout much of the cassava growing regions of Africa causing severe yield reductions (Herren, 1981). *P. herreni* a very closely related species is causing considerable damage in certain areas of the Americas, especially the northeast of Brazil (Bellotti, 1983; Bellotti *et al*, 1983). The feeding of these mealybugs causes leaf yellowing and curling, defoliation, and with high infestations, green shoot death. Recent studies indicate that root losses can reach 87% (Herren, 1981; CIAT, 1985).

Resistance studies for these two species are in progress at IITA in Africa, CIAT in the Americas, and IPA (Instituto Panambucana Agropecuaria) in Brazil. The evaluation of germplasm is based mainly on damage scales, with artificial and natural infestations, under field conditions. It has been shown that resistant sources exist in both the cultivated species (CIAT, 1980, 1984; IITA, 1981; Hahn, 1983; Ezumuh and Knight, 1980) and in several related species (Hahn, 1982b; Albuquerque, 1977). Several clones within cultivated cassava, which decrease the mealybug population on the plant, has been identified at IITA and is being used in the breeding program (IITA, 1981; Hahn 1982a). A relationship between hair density on the leaf and resistance to the mealybug has been shown.

More than 2000 varieties in the CIAT cassava germplasm bank were evaluated in the field during a natural infestation of the mealybug, *P. herreni*. Over 500 cultivars, about 24%, showed no damage symptoms; many of these undoubtedly being escapes. Further evaluation of these cultivars is being continued (CIAT, 1984).

## Whiteflies

Whiteflies are important in cassava primarily because they are vectors of several virus or mosaic diseases. However, it has also been shown that high whitefly populations can cause severe yield reductions (CIAT, 1980, 1981,1982;Vargas and Bellotti, 1981). Yield losses reached 79% during an 11 month attack of the whitefly species *Aleurotrachelus socialis*. Other important species in the Americas are *Aleurothrixus aepim, Bemesia tuberculata* and *Trialeurodes variabilis*. It is not certain which of these species in most important in virus transmission. *Bemisia tabaci* the most important species in Africa and India and the vector of African Cassava Mosaic disease has not been reported feeding on cassava in the Americas.

Screening for resistance to whiteflies at CIAT has been for *A. Sociales*, the species causing greatest yield losses in the Americas. Approximately 1400 cultivars from the CIAT germplasm bank have been screened under high field populations of the whitefly. About 50 cultivars have been selected as promising for resistance and 5 have been identified as resistant. These have entered into a hybridization program and the progeny are being evaluated (CIAT, 1976, 1977, 1982, 1983, 1984, 1985). Initial results of these crosses show high levels of whitefly populations for progeny of resistant x susceptible crosses but only a moderate level of damage symptoms. The resistant x resistant progeny show a moderate whitefly population but a very low level of damage symptoms (CIAT, 1982). Results of greenhouse studies on resistance mechanisms indicate that ovipositional preference as well as antibiosis may be responsible for whitefly resistance (CIAT, 1982).

Lace bugs

The cassava lace bugs, *Vatiga, manihotae* and *V. illudens* are reported feeding on cassava in several countries of the Americas. Lace bug attack manifests itself during the dry season when high populations can cause considerable defoliation. Leaves have yellow spots that eventually turn reddish brown, resembling *Tetranychus* mite damage. Yield losses are note known (Bellotti and Schoonhoven, 1978).

Approximately 2000 lines of the CIAT germplasm bank have been evaluated during two seasons with natural infestations of *V. manihotae* in the field. These evaluations have resulted in 131 lines being selected as promising for resistance. Evaluations under high field infestations still needs to be done to accurately determine resistance.

Screening for resistance to the lace bugs species *V. illudens* is being done in Brazil (Cosenza *et al*, 1981; EMBRAPA, 1982). Results indicate that lacebug resistance exists and several varieties have been selected. Greenhouse studies indicate that non-preference and antibiosis may be the resistance mechanism involved.

Other pests

A review of the literature shows that resistance has been reported for several additional cassava pests. These include scales, stemborers, shoot flies, grasshoppers, gall midges and fruit flies (Bellotti and Kawano, 1980; Bellotti and Schoonhoven, 1978). Most involve field observations under natural infestations; few involve replicated trials nor are they part of a continuing research program.

454

Although HCN content has often been speculated as a resistance factor in cassava, little evidence exists to support this speculation. However, some observations have been made that indicate certain insects prefer low HCN cultivars over the high HCN ones. Recent studies at CIAT show that the subterranean sucking insect, *Cyrtomenus bergi*, the nymphs and adults of which feed on cassava roots, strongly prefer low HCN or sweet varieties over the high ones. When given a free choice in both laboratory and field studies, the insect had a strong feeding preference for the low HCN cultivar. Only 0.3% of the roots of MCol 1684 (high HCN) were damaged while 27.3% of those of CMC-40 (low HCN) were damaged in field studies (CIAT, 1984, 1985).

## Techniques for evaluating cassava germplasm

A breeding program that involves host plant resistance to insects and mites must begin with an extensive, working germplasm collection. The CIAT cassava germplasm collection contains more than 3800 accessions, with considerable genetic variability available. This collection is mostly comprised of varieties grown by traditional cassava farmers throughout the Americas. The collection, therefore, should contain accessions that have been selected by farmers for many years to withstand the pests or diseases prevalent in a given ecosystem (Lozano *et al*, 1980). Germplasm collections suitable for screening for pest or disease resistance are available at several institutions but none are as extensive as the CIAT collection. Additional sizable collections are at CNPMF (Centro Nacional de Pesquisa de Mandioca y Fruticultura) in Brazil (more than 700 vegetative accessions), at IITA in Nigeria (2000 + accessions in seed form) and at CTCRI (Central Tuber Crops Research Institute) in India (1800 vegetative accessions). At present, there are at least 15 countries in the Americas, 1 in the south Pacific, 7 in Asia, and 5 in Africa that have local cassava collections that are actively maintained for breeding or agronomic studies (CIAT, 1980b).

The evaluation of cassava germplasm for insect and mite resistance involves an interaction between the plant and the pest. Thus cassava resistance to pests can be studied in two dimensions, one being the variation that takes place in the cassava plant due to pest attack, and the other is the variations expressed in the pest populations as a result of its feeding on the host. The design of an evaluation scheme or research method should, therefore, make it possible to measure or quantity these variations, especially those that occur in the cassava plant. If the resistance is to be incorporated into a breeding program, than it is additionally important to be able to estimate the source of the variance, or the mechanism involved, as well as the heritability of the trait or traits identified. Thus it is equally important to have an intimate knowledge of

the biology and feeding habits of the insect.

A review of the literature indicated that numerous crite-
ria (see Ortman and Peters, 1980) have been used to evaluate
insect resistance in cassava. These include:

1. Visual evaluation of infested cultivars, observing
leaf speckling, discoloration and distortion, retarded plant
growth stem distortion and length of internodes (mites, thrips,
mealybugs, lace bugs, whiteflies, shoot flies, fruit flies).

2. Determination of the difference in yield between infest-
ed and non-infested plots (thrips, mites, mealybugs, whiteflies).

3. Determination of the number of insect, larvae or nymphs
attracted to a cultivar when given a free choice (whiteflies,
stemborers, mites, mealybugs, lace bugs).

4. Measurement of amounts of root surface discolored due
to insect feeding (subterranean sucking insect).

5. Observation of the comparative effects of forced insect
feeding (in confinement) on plants or cultivars by measuring
length of insect life cycle, mortality, or reproductive rate
(mites, mealybugs, whiteflies, stemborers and lace bugs).

6. Weight of insects after definite feeding period on dif-
ferent cultivars (mealybugs).

7. Determination of number of eggs laid (mites, hornworm,
lace bugs, fruit flies, whiteflies).

8. Determination of number of surviving insects and proge-
ny produced (mites, mealybugs, whiteflies, lace bugs).

9. Correlation of morphological factors with injury (thrips,
mites, mealybugs).

10. Measurement of amount of food utilized by insect (mites,
hornworm, grasshoppers).

In initial studies of cassava germplasm it is important to
examine large quantities of diverse material. In general, if
there is an adequate infestation, reliable evaluation for resis-
tance can be done in small plots (1 to 5 plants) and often with
seedling plants. Single plant seedling or small plot selection
for resistance (or to determine susceptibility) is routinely
done for mites (IITA, 1980; CIAT, 1979; Bernardo and Esguerra,
1981b), thrips (CIAT, 1978; Bellotti and Kawano, 1980), lace
bugs (CIAT, 1979, 1981), mealybugs (CIAT, 1984; IITA, 1981),
and others. In these initial studies the essential goal is to
eliminate the bulk of susceptible material. Additional cycles
of evaluations are used to confirm the preliminary evaluations

which have selected promising materials. This procedure has been used in cassava with mites, thrips, mealybugs, lace bugs and whiteflies. It reduces the number of genotypes that must be evaluated for yield depression in large, replicated, plots.

There are several important aspects and techniques involved in a resistance evaluation and breeding program for cassava pests. These are discussed in detail by Bellotti and Kawano (1980) and will therefore, only be summarized here.

1. The critical aspect of resistance evaluations is to have sufficiently high levels of the pest present to be able to distinguish between resistant and susceptible genotypes. It is important to select a site where the pest, due to ecological reasons, is epidemic on an annual basis.

2. Cultivars should be planted to coincide with maximum pest pressure.

3. Field populations of pests can be augmented by artificial inoculations from pest colonies.

4. The planting of susceptible border rows will aid in an even and high pest population.

5. A reliable rating scheme with various levels of damage discrimination is needed to distinguish resistant and susceptible material. In initial studies this is usually a 0 to 5 scale that describes progressively worse foliage and plant damage.

6. Later evaluation studies should permit a more precise definition of the level and expression of resistance.

7. Greenhouse or screenhouse evaluation procedures have been used for certain pests. They have been successful in mite screening because these evaluations have been comparable to field results (Byrne, 1980). However preliminary results with greenhouse screenings for mealybugs resistance at CIAT has not been successful.

8. Rating schemes can also measure insect populations when damage symptoms are not sufficiently pronounced to evaluate accurately. They are useful if the insect is easily detected so that rapid field evaluations can be made.

SCREENING CASSAVA GERMPLASM FOR RESISTANCE TO INSECTS AND MITES

The procedures used for screening cassava germplasm for resistance to mites (*Mononychellus* spp.), thrips, whiteflies, mealybugs and lace bugs will be briefly described (see Bellotti and Kawano, 1980, for additional details). The damage rating scheme

presently in use at CIAT will be described. Damage rating schemes being used by other workers are similar in that usually a 0 to 5 scale that describes progressively worse foliage and plant damage is employed (IITA, 1981; Cruz, 1981; Farias *et al*, 1981; Bernardo and Esguerra, 1981b; Cosenza *et al*, 1981; Bellotti and Kawano, 1980).

## Mites (*Mononychellus* spp.)

In the initial screening phase the main objective is to eliminate about 80 percent of the cultivars and reevaluate the remainder. These species primarily feeds on the upper leaves of the plant, especially on leaves emerging from the bud. They causes yellow to white speckling and deformation of leaves.

Stem cuttings 2 inches long are planted in 4-inch diameter plastic pots. Approximately 1 month after germination they are removed to the greenhouse (30 to 34°C) and placed in large (1 x 2 m) plastic screening cages, 60 plants to a cage. Two weeks later, they are infested with mites. Each pot represents one variety, and the variety may be repeated several times in one cage or different cages (CIAT, 1976).

Infestation is done by placing one or two lobes of a mite-infested cassava leaf (50 to 100 mites) on the upper leaves of each test plant. Mites from the field are regularly reintroduced into the colony. Damage evaluations are made beginning the second week after infestation, and each week thereafter for four consecutive weeks. Second and third inoculations are made if the initial one is not successful. A 0 to 5 damage scale based on these symptoms is used during this initial phase:

0 = No mites or symptoms

1 = Mites on bud leaves, some yellow to white speckling of leaves

2 = Many mites on leaves, moderate speckling of bud leaves and adjacent leaves

3 = Heavy speckling of terminal leaves, slight deformation of bud leaves.

4 = Severe deformation of bud leaves, reduction of bud, mites on nearly all leaves, with whitish appearance and some defoliation.

5 = Bud greatly reduced or dead, defoliation of upper leaves.

Those cultivars selected as promising for resistant are planted in areas where mite attacks are endemic (Guajira, Colom-

458

bia). Replicated block with susceptible border rows was used.
For field evaluation the 0-5 scale was converted to the 1 to
8 scale described below (Byrne, 1980):

| 0 - 5 scale | 1 - 8 scale | Amount of Damage |
|---|---|---|
| 0 A 0.50 | 1 | None to very slight |
| 0.50 A 1.50 | 2 | Slight |
| 1.50 A 2.25 | 3 | Slight - intermediate |
| 2.25 A 2.75 | 4 | Intermediate |
| 2.75 A 3.25 | 5 | Intermediate - severe |
| 3.25 A 3.75 | 6 | Severe |
| 3.75 A 4.25 | 7 | Very severe |
| 4.25 A 5.00 | 8 | Terminal shoot dead |

1 = rating according to 0 - 5 scale

Correlation between blocks within experiments and between
experiments were similar as was the correlation between green-
house and filed screening (Byrne, 1980). This indicates that
the variety by site interaction is less important than the var-
ietal effects. Thus the resistance to *Mononychellus* sp. is re-
latively stable across environments (CIAT, 1979). In addition
yield trial were carried out to determine the differential ef-
fect of mites on susceptible and resistant cultivars. Yield
reduction in resistant varieties (protected vs. non protected
plots) was nonsignificant at 15% while reductions in suscept-
ible varieties averaged 70% (CIAT, 1979).

### Thrips (*Frankliniella williamsi*)

The symptoms of thrips damage are much more pronounced dur-
ing the dry season, although the insects are present throughout
the year. The procedure for evaluating resistance to thrips in
cassava was developed by Schoonhoven (1974). The CIAT germplasm
collection was evaluated under natural infestation during three
dry seasons for thrips damage (CIAT, 1977). Plants were evalu-
ated at 4 and 8 months, and an average of these two assessments
was used as a resistance classification. Symptoms of thrips
damage were classified into six reaction classes:

0 = No symptoms

1 = Yellow irregular leaf spots only

2 = Leaf spots, light leaf deformation, parts of leaf lobes missing, brown wound tissue in spots on stems and petioles.

3 = Severe leaf deformation and distortion, poorly expanded leaves, internodes stunted and covered with brown wound tissue.

4 = As above, but with growing points dead, sprouting of lateral buds.

5 = Lateral buds also killed. Plants greatly stunted, with witches' broom-type appearance.

The nature of thrips resistance was studied on 8-month-old nonflowering clones representing each of the resistance levels. Thrips populations were determined by collecting three terminal buds from single plants in a plastic bag, immersing them in 30 percent alcohol, and counting the insects under a microscope. Plant pubescense was determined by counting the number of hairs on the undersurface of one side of an unexpanded leaf lobe. Two leaves per plant were sampled when leaves measured about 1 cm in length. It was found that the leaves of susceptible clones had few or no hairs whereas the leaves of resistant clones had many. Thrips were found on all clones regardless of resistance, but fewer were found on resistant ones. No correlation was found between thrips resistance and plant cyanide content, thus enabling a combination of thrips resistance and low cyanide content.

## Whiteflies (*Aleurotrachelus sociales*)

The pupal stage of *Aleurotrachelus* sp. is oblong and black, with a white waxy excretion around the outer edge, and is easily seen on the leaf undersurface. Cassava lines are screened in an area having heavy natural infestations. Ten plants of each line are sown in two replicates of five plants each, and rows of susceptible varieties are dispersed throughout the field. Evaluations are made every 2 months beginning when the plants are 2 months old.

Resistance evaluation uses three 0 to 5 scales for (1) the number of pupae per leaf; (2) the percentage of leaves infested with pupae; and (3) damage symptoms caused by whitefly feeding. The number of pupae per leaf is recorded by sampling three leaves per plant:

460

Pupal scale:

    0 = No pupae

    1 = Less than 50 pupae per leaf.

    2 = 51 to 100 pupae per leaf.

    3 = 101 to 250 pupae per leaf.

    4 = 251 to 500 pupae per leaf.

    5 = More than 500 pupae per leaf.


    The percentage of infested leaves per plant is determined by examining several leaves at various plant levels:

Population scale:

    0 = No infestation.

    1 = Less than 20 percent infested.

    2 = 21 to 40 percent infested.

    3 = 41 to 60 percent infested.

    4 = 61 to 80 percent infested

    5 = 81 to 100 percent infested


Damage symptoms are recorded as follows:

    0 = No damage.

    1 = Slight speckling of lower leaves.

    2 = Heavy speckling of lower leaves.

    3 = Mosaic-like symptoms on leaves but little wrinkling, sooty mold on lower and central leaves.

    4 = Wrinkling and yellowish mottling of lower and apical leaves, some leaf necrosis, considerable sooty mold.

    5 = Severe wrinkling of apical leaves and leaf necrosis.


    These three scales permit correlation of damage symptoms with whitefly numbers. Large whitefly populations with few damage could indicate that a tolerance mechanism is involved.

In this case a damage symptom evaluation alone would not neces-
sarily indicate the whitefly population. Tolerant varieties
would not reduce whitefly populations, which be the main goal
of a resistance program aimed at reducing virus transmission.

Lace bugs (*Vatiga manihotae*)

Evaluation for lace bug resistance was done in the cassava
germplasm bank for two successive years using natural infesta-
tion. The following damage scale was used:

0 = No lace bug present

1 = A few yellow sports on lower leaves.

2 = Many spots on lower leaves; leaves turn yellowish.

3 = Many yellowish red spots on leaves; lower leaves curl.

4 = Lower leaves curl and dry up; intermediate leaves curl.

5 = Defoliation of basal and intermediate leaves; apical
    leaves turn yellow.

Mealybugs (*Phenacoccus herreni*)

Initial screenings for mealybug resistance were done in
the greenhouse (average temperature 24°C and 70% RH). Two 4-5
week old plants of each accession grown from stem cuttings were
inoculated by placing two mealybug ovisacs on the growing point.
Evaluations were made 2 and 4 weeks later and mealybug counts
as well as damage symptoms were recorded. Eight hundred varie-
ties were evaluated using this methodology. Results were dis-
appointing as some varieties expressing resistance under green-
house screening proved very susceptible under field screening
(CIAT, 1985). New methodology for field screening is now being
developed. One drawback to field screening is that mealybug po-
pulations are often not high enough nor evenly distributed.
Artificial infestation from a greenhouse mealybug colony to
field cultivars has had mixed success. Initially egg masses
were placed in the growing shoot at the onset of the dry season.
These egg masses were heavily predated upon by the ample complex
of natural enemies that exists at CIAT, therefore, adequate
field populations often do not develop. A system utilizing
small leaf cages to protect the egg masses and infesting the
lower leaves has proved more successful.

More than 2000 varieties in the CIAT cassava germplasm bank
were evaluated in the field during a natural infestation (CIAT,
1984). The following damage rating was used:

462

0 = No symptoms

1 = Apical leaf margins undulate

2 = Slight curling of new leaves, stem development normal.

3 = Deformation and yellowing in most new attacked leaves appearing cabbagelike, with a slight shortening of internodes.

4 = Death of some leaves, drastic shortening of internodes, terminal stems spiral shaped, flower petiole reduced, presence of sooty mold.

5 = Death of buds, defoliation, abundant sooty mold, plant development stunted.

Approximately 60% of the accessions had a damage rating of 3 or above and were described as susceptible. Those accessions with a lower rating will be reevaluated in the field under both natural and innoculated conditions.

EDAPHO-CLIMATIC ZONES AND INSECT COMPLEXES

Cassava is grown under a wide range of environmental conditions in the tropical and semi-tropical regions of the world. In recent years both CIAT and IITA have tried to define the characteristics, both climatic and edaphic define these regions. CIAT has delineated six combinations of edapho-climatic characteristics which appear to constitute a necessity for basically different genotypes (Huskey, 1983; Lozano *et al*, 1980). Edaphoclimatic zones (ECZ) are defined on the basis of temperature, rainfall distribution and soil characteristics. The potential importance of pests and diseases in cassava is largely dependent upon climatic and soil conditions of a region, along the presence of a susceptible host and cultural practices.

Each ECZ, therefore, can be identified with a unique combination of disease and insect pest problems (Lozano *et al*, 1983). For example low to moderate rainfall with prolonged dry periods (3-6 months) and high temperatures are characteristic of ECZ I. The pest complex that correspond to these conditions include mites, thrips, mealybugs and lace bugs. Combinations of these pests in sufficiently high populations to cause severe yield reductions, can be found in several areas of the Americas (the north coast of Colombia, the north east of Brazil and northern Venezuela). Ideally, selected clones for these regions should have a balanced resistance to all of the important pests and

463

disease problem of each ECZ.

The overal cassava breeding strategy at CIAT in relation to pest and disease complexes consists of: (1) germplasm accession evaluation in diverse ECZ's in Colombia; (2) parental selection and formation of gene pools for each ECZ based on performance of germplasm accessions; (3) hybrid evaluation and selection primarily within but also across ECZ's; and (4) recommendation to national programs for testing of selected clones and/or progeny of specific crosses (Hershey, 1983).

The principal evaluation and selection sites should combine as many of the potential stress factors as possible for the particular edaphoclimatic zone in order to make the final selected products as broadly relevant as possible within similar regions. In terms of insect and mite resistance evaluation emphasis is given to selection for a broad, combined tolerance/resistance to the yield limiting pests within each ECZ, as well as disease tolerance high yield potential and good root quality. The end result is to have clones with a broad adaptability within each ECZ. Clones have been developed with combined tolerance or resistance to mites and thrips and potentially will also include mealybugs and lace bugs.

BREEDING METHODOLOGY

Under traditional farming systems in which cassava has evolved, isolation and cultural practices aided in keeping pest presssure at relatively low levels. In these systems only low or intermediate host resistance levels were necessary. For intensified cultural practices and extended cassava growing areas, higher resistance levels are often required.

Cassava is a monoecious species, with both male and female flowers on the same plant. This along with the fact that female flowers open about two weeks before male flowers, results in high levels of natural outcrossing. Nevertheless, when an individual clone is planted in large plots, the possibility increases for intercrossing among plants of the same clone, which is genetically the same as selfing.

All cultivars appear to be highly heterozygous, based on wide segregation of progeny, and on high levels of inbreeding depression. Cassava is generally considered to be an allotetraploid, but seems to behave as a functional diploid for most characters. Vegetative propagation allows fixation genes in heterozygous plants at any stage of a breeding program. Thus, any character identified in an individual plant can be indefinitely propagated.

464

Little information exists on the genetics of resistance to insect and mite pests in cassava. Heritability studies for *Mononychellus* sp. mites, and thrips have shown predominantly additive variance on the basis of parent-progeny regression analysis (Byrne, 1980; CIAT, 1981; IITA, 1981). On the basis of segregation patterns, resistance appears to be multigenic for all pests so far studied, though definitive genetic studies have not been done. These preliminary studies suggest a population improvement scheme will be most effective in breeding for insect and mite resistance. Crosses between genotypes with resistance genes at different loci, each having additive effects should result in higher resistance levels in some proportion of the progeny. A recurrent selection scheme which allows accumulation of these additive effects appear to be the most effective strategy.

A critical aspect of breeding for resistance is to begin with an adequate germplasm base. First, locally available clones should be evaluated for the existing pests. If adequate resistance exists, there may be no need to introduce new germplasm. However, many programs will benefit from well-selected introductions from national or international germplasm collections. The introductions can take various forms: (1) clones with identified resistance; (2) progeny (true seed) from clones with identified resistance; and/or (3) progeny (true seed) which have been evaluated on a family basis for resistance. Generally clonal introductions can best be utilized in crosses with locally adapted material, while seed introductions, if large enough in number, can often be directly selected for resistance and local adaptation due to large variability represented.

In many regions, more than one insect or mite problem exists, and multiple resistance must be sought. For each additional character a breeder wants to improve, the rate of progress which can be achieved decreases rapidly. This again emphasizes the importance of a careful prioritization of problems for breeding. For most programs, breeding for resistance to the key pests will be a sufficient challenge. As for most multiple breeding objectives, it is generally more efficient to select simultaneously for the different resistances within the same population rather than to breed for high resistance to individual pests in separate populations with later recombination.

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# CASSAVA DISEASES AND THEIR CONTROL[1]

## INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is of South American origin, with a secondary center in Guatemala and Mexico. It was possibly domesticated since more than 5000 years ago. The species is composed of many clones which are under cultivation and show great diversity of morphological characters. It is cultivated vegetatively by planting mature stake cuttings of several clones in a mixcropping or monocropping system.

Cassava has been considered a rustic crop resistant to both diseases and insects as well as to edaphic and climatic conditions. It is found in areas from 0 to 2000 meters elevation, but its clones are adapted specifically to locations where they were developed. The introduction of clones to areas with different ecological conditions evolved may severely reduce their performance.

The average of cassava yield is of 10 ton/ha, but in experimental trials yields of more than 40 ton/ha are commonly reported. It is undoubtedly that the stress asserted by pathogens and pests has in a high percentage the responsibility for this great difference. When planting material is selected according to its sanitary condition and few cultural practices are given to plantation to reduce disease and pest incidence yields have increased in more than 3 times.

Due to the shortage of carbohydrates for human and animal consumption as well as for industrial purposes cassava cultivation has been expanded considerably; similarly, the monoculture system is now widely used. These have obviously increased the sanitary problems of the crop considerably, causing in certain regions severe epiphytoties which in some cases the crop has been almost completely eliminated. This paper attempts to gather much of the information available on cassava diseases as well as to present it with recent observations made by the authors as a contribution for increasing and stabilize yields of this important crop.

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1    Pathology section is compound of several articles from
     several authors which is presented into this book content.

# CASSAVA/ECOSYSTEM RELATIONSHIPS AND THEIR INFLUENCE ON BREEDING
## STRATEGY

Cassava (*Manihot esculenta* Crantz) originated in America with a major centre of diversity in South America and a secondary centre in Guatemala and Mexico (Leon, 1977; Lozano, 1977), where it has been cultivated for more than 5000 years. Some 400 years ago the crop was introduced in Africa and more recently in Asia (Jennings, 1976; Leon, 1977; Mauny, 1953). It is composed of clones under cultivation; no wild types have been found (Leon, 1977).

The species has 36 chromosomes and is generally regarded as tetraploid (Toro and Garcia, 1977). Clones are highly heterozygous (CIAT, 1976; Kawano *et al*, 1978) but not heterogeneous, mainly because of vegetative propagation and inbreeding depression.

In a multiclonal population cassava has a very high rate of selfing (Kawano *et al*, 1978). Plants grown from botanical seed do not compete well with those grown from vegetative cuttings or with weeds; thus plants from true seed are not common in traditional farming systems.

Cassava has been traditionally cultivated under mixed cropping systems where stem cuttings of different clones are planted on recently cleared land. This system is still being used to a great extent in the Americas (J.K. Lynam, personal communication). Monocropping has only recently been introduced, but still with the traditional multiclonal cassava population.

These early plantations were isolated, locally by forests and regionally by mountains. The american cassava-growing areas are characterised by a great diversity of edaphic and climatic conditions. Soils vary in pH (3.0-9.5), texture, macro- and/or micronutrient deficiencies, salinity or mineral toxicity, e.g., aluminium, and organic matter content. Climatic conditions are often dependent on elevation, except for Paraguay and south-eastern Brazil and Peru; temperatures can be stable or fluctuating, averaging from 8 to 33°C; there are equatorial to subequatorial photoperiods; semi-desert to very wet regions (500-6000 mm/year) with 1 or 2 rainy or dry periods of 1 to 8 months/year; and relative humidities ranging from 15% to near saturation during a given period of the year. All these factors combine to form a great number of different ecosystems.

Due to their relative isolation, farmers usually plant vegetative material obtained from a previous crop or from neighbouring farms. Clone introductions have occurred only occasionally, each being selected by the farmer on comparison with the

performance of local clones as regards adaptation to the ecosystem, yield stability and resistance to diseases and pests found in the new ecosystem.

Although research has shown that *M. esculenta* has a high yield potential (Cock, 1974; Kawano, 1978), commercial yield/ unit area is very low (FAO, 1971). This has been generally attributed to inadequate agronomic practices, as well as to the lack of improved, high-yielding cultivars resistant to diseases and attack by pests. Great advances in cultural practices have been reported (CIAT, 1976, 1977, 1978, 1979; Toro and Garcia, 1977), but promising selections or improved lines have given variable results when grown in regions other than those from where they were selected. This suggests that regional testing of varieties and programmes for incorporating specific resistance to the different pressures or negative production factors (NPFs) in a given ecosystem are required.

The relationship between the cassava plant and the NPFs existing in the different cassava-growing areas are studied on the basis of experimental results obtained over the past 10 years at CIAT, with emphasis on pathological problems; their impact on breeding strategies is discussed.

BREEDING PROGRAMMES: IMPACT OF PAST STRATEGIES

Cassava breeding programmes are relatively recent; one of the first was initiated 50 years ago at the Instituto Agronómico de Campinas, Brazil (Normanha and Pereira, 1950). Later a breeding programme in Africa began work on the development of varieties resistant to African mosaic disease (Storey and Nichols, 1938). During the past decade, the International Institute of Tropical Agriculture (IITA), Nigeria and the Centro Internacional de Agricultura Tropical (CIAT), as well as several national programmes, initiated breeding projects (Mauny, 1953; Nestel, 1974).

IITA's breeding programme involves massive crossing and selection against two major diseases, cassava bacterial blight (CBB) and Agrican mosaic disease, and their dissemination. Improved true seed from different interpollinated superior females with sources of resistance and other agronomic traits is sent to different locations in Africa. CIAT's programme has used conventional crossing of superior lines following a pedigree method; selected material at one centre is vegetatively disseminated and tested in three different locations.

The impact of these programmes on the species to date, however, has been limited. Regional cultivars probably have most of the genetic traits characteristic of the first domesticated and selected clones, having been selected over the centuries for

473

ecological adaptability, resistance to diseases and pests, and good agronomic characteristics. These clones constitute an excellent source of basic material for breeding programmes, the success of which depends on their correct identification and use.

EXPERIMENTAL RESULTS RELATED TO BREEDING STRATEGIES

Results of research over the past ten years have led us to believe that (a) disease and pest incidence and severity of attack are related to the ecological characteristics of a given region; (b) pathogenic race specialisation among cassava diseases appears to be rare; (c) stable resistance to most major NPFs exists in *M. esculenta*; (d) clones in existence today are regionally adapted cultivars that have persisted in a given ecosystem because of certain desirable characters; and (e) clones with resistance to the main NPFs in an ecosystem can be found.

Recent studies have shown that diseases and pests are often restricted to certain regions, and if present, become severe only during a certain season. Cercospora leaf spots, *Cercosporidium* (Cercospora) *henningsii* Allescher and *Cercospora viscosae* Muller and Chupp, anthracnose, *Colletotrichum* and *Gloeosporium* spp., and rusts, *Uromyces* spp., are not found or are only mild during dry periods or in semi-desert regions (CIAT, 1976; Lozano, 1978; Lozano and Booth, 1974; Teri, Thurston and Lozano, 1978); whereas CBB, *Xanthomonas manihotis* (Arthaud-Berthet & Bondar) Starr, and superelongation, *Sphaceloma manihoticola* Bitanc. & Jenk. are severe only during periods of prolonged rainfall (Krauz, Lozano and Thurston, 1978; Lozano, 1975; Lozano, 1978). Moreover, CBB infection is moderate in areas where temperatures are stable, independent of the rainy season or the amount of rainfall in a given period (CIAT, 1979; Takatsu, 1977). Concentric-ring leaf spot, *Phyllosticta* spp., and white leaf spot, *Phaeoramularia manihotis = Cercospora caribaea* Chupp and Ciferri, occur in regions where temperatures fall below 18°C during the rainy season and during the winter in the subtropical zones of southern Brazil and Peru, northern Argentina, Uruguay and Paraguay (Lozano and Booth, 1974). Phytophthora and Pythium root rots are most prevalent in heavy, undrained soils (Booth, 1978; Lozano and Booth, 1974; Oliveros, Lozano and Booth, 1974), whereas Armillaria, Rosellinia and Rigidoporus root rots cause heavy losses when cassava is planted following forest or perennial crops (Booth, 1978; Lozano and Booth, 1974). Stem rots are severe in areas where relative humidities are near saturation for prolonged periods. Incidence of African mosaic is particularly high when there are high populations of its vector, *Bemisia* spp., in the rainy season (Bock and Guthrie, 1977; Leuschner, 1977). This is also the case in bacterial stem rot caused by *Erwinia carotovora* var. *carotovora* (Jones) Bergey *et al*, found in association with fruit-

474

flies (Lozano and Bellotti, 1979). Populations of mites, thrips and lacebugs are particularly high when there are prolonged dry periods (Bellotti and van Schoonhoven, 1978). With one exception (CIAT, 1978, 1979; the causan agent of superelongation, which possibly evolved on a different euphorbia host(s)), to date there does not appear to be any evidence of race specialisation among cassava pathogens. Our research on the pathogenic variability of the causal agents of bacterial blight, Cercospora leaf spots (three species), concentric-ring leaf spot and anthracnose (three species of *Colletotrichum* and two of *Gloeosporium*) have shown that their variability is due to aggressiveness, not to a gene-for-gene relationship with their host.

This apparent lack of race specialisation could be due to the fact that cassava, a homogeneous long-season crop (8-18 months) is basically heterozygous (CIAT, 1976; Kawano *et al*, 1978) and that its major pests are not obligate parasites.

Resistance to NPFs, particularly diseases and pests, appears to be stable, which is to be expected in regional varieties be-cause those with unstable resistance could not survive in a crop that has relatively static genetic composition and in which sus-ceptible material is always present. Assuming that pathogens and pests have a greater capacity for genetic change than this vege-tatively propagated crop, theu would overcome resistance faster that the crop could evolve it.

In the Caicedonia area in Colombia, for example, the variety Chiroza has given steady yields of around 26 t/ha over the last seven years (S. Garcia, personal communication). Llanera in the eastern plains region and Valluna in Santander de Quilichao have been giving consistent yields for many years, supporting the sta-tement that stable resistance does exist and has been exploited by farmers for many years.

Clones grown in traditional systems are regionally adapted, having been selected over time in ecosystems with distinct sets of NPFs. Clones selected and developed in areas where there are few NPFs usually give steady yields at these sites; but when grown in other ecosystems, these same clones tend to show greater fluctuation in yield from year to year (Table 1). This is due to the fact that varieties selected in areas with few NPFs do not have resistance to all the NPFs at other sites; therefore, yields will vary, depending on the stress exerted from one year to an-other.

Considerable decrease in yield have been recorded when a regionally adapted variety is grown in another ecosystem with different NPFs. An example is the case of lines CMC 92 and MCol 22, the former adapted to the Popayan region of Colombia and the latter adapted to CIAT conditions (Table 2). When CMC 92 was

grown at CIAT, its yield decreased from 20 to 8 t/ha. Yields of MCol 22 fell from 40 to almost nothing (0-1 t/ha) when grown at Popayan. The same has been recorded for the variety Santa Catarina in Brazil (A. Takatsu, personal communication) and several varieties from Kenya when planted elsewhere in Africa (E. Terry, personal communication).

Resistance to most NPFs existing in the different ecosystems probably exists in *M. esculenta* since it has been selected under a wide range of ecosystems. The highest expression of resistance is found where stress due to NPFs is highest. Thus far, clones

TABLE 1.   FLUCTUATION IN YIELDS OF MATERIALS SELECTED AT CIAT AND PLANTED AT EIGHT LOCATIONS IN COLOMBIA OVER THREE YEAR PERIOD (1975-1977).

| Site | Mean yield (t/ha) | Variation s.d. | Standardised variation c.v. |
|---|---|---|---|
| Medialuna | 12.7 | 5.0 | 39.7 |
| Carimagua | 15.3 | 9.1 | 59.2 |
| Nataima | 23.3 | 6.0 | 25.8 |
| Rio Negro | 23.3 | 6.5 | 27.8 |
| Caicedonia | 31.0 | 10.5 | 34.0 |
| Pereira | 29.3 | 11.6 | 39.5 |
| Popayan | 9.0 | 2.7 | 29.4 |
| CIAT | 31.0 | 3.0 | 9.7 |

with resistance to the following adverse factors have been reported: low levels of phosphorus, high levels of aluminium, saline soils (Howeler, 1978); stable low temperatures (Irikura, Cock and Kawano, 1979); *Cercospora* spp, *Colletotrichum* and *Gloeosporium* spp., *Sphaceloma manihoticola* (Kraus, Lozano and Thurston, 1978; Lozano, 1978; Lozano and Booth, 1974), African mosaic (Bock and Guthrie, 1977; Hahn, 1979), mites, thrips and lacebugs (Bellotti and van Schoonhoven, 1978; CIAT, 1979).

RESISTANCE TO SPECIFIC SETS OF NPFs.

Although sources of resistance to all major diseases, as well as to several insects, and tolerance to adverse edaphic and climatic conditions have been identified, combining these characters into one variety poses a serious problem for breeding programmes since it requires a large number of crosses and several generations of testing. Consequently, emphasis has been placed on identifying lines tolerance to many NPFs. Work at CIAT has concentrated on two regions in Colombia, each with different adverse factors that can greatly reduce yield (Table 1).

Popayan Ecosystem

The major NPFs at this site are leaf spot diseases, low temperatures and low soil pH. Reactions of a resistant line, CMC 92, an intermediate line, CMC 39 (resistant to low temperatures and pH but not to leaf spot diseases), and a susceptible line, MCol 22, were studied over a 5-year period (Fig.1).

The susceptible line consistently yielded from 0-1 t/ha, whereas that of the intermediate line fluctuated between 8 and 26 t/ha, depending on the intensity of disease present, mainly determined by amount of rainfall (Table 3). The resistant line consistently yielded 18-22 t/ha.

In a two-year screening trial, it was shown that yield was related to resistance to the NPFs in this ecosystem (Fig.2). In the second year, four lines that had been rated as susceptible the first year appeared to be resistant since they yielded as well as the resistant lines. Further studies revealed that they were resistant to the edaphic and climatic constraints, but not to the disease problems (CIAT, 1979). Since the second year was abnormally dry, there were few disease pressures; thus these varieties yielded well.

Carimagua Ecosystem

Although this area is representative of much larger areas with a tremendous potential for increased production, there are many NPFs, such as bacterial blight, superelongation, low soil fertility, low pH, aluminium toxicity and mites (Table 2). In selection trials of 800 clones over a two-year period, eight were selected as resistant.

TABLE 2. SOME NEGATIVE PRODUCTION FACTORS (NPFs) THAT REDUCE YIELDS IN FOUR DIFFERENT ECOSYSTEMS IN COLOMBIA

| NPFs | Location | | | |
|------|----------|--|--|--|
|      | Popayan | Darien | Carimagua | CIAT |
| **CLIMATIC CONDITIONS** | | | | |
| Mean temperature (°C) | 18.0(+)* | 19.5(+) | 26.1(-) | 24.0(-) |
| Rainfall (mm/year) | 2500(-) | 1500(-) | 2031(-) | 1000(+) |
| Rainfall duration (month) | 6 (2 periods)(-) | 6 (2 periods)(-) | 8 (1 period)(+) | 5(2 periods)(-) |
| **EDAPHIC CONDITIONS** | | | | |
| pH | 4.1(+) | 4.3(+) | 4.7(+) | 6.8(-) |
| Al concentration | High(+) | High(+) | High(+) | Low(-) |
| Fertility | Good(-) | Medium-low(+) | Low(+) | Good(-) |
| Texture | Clay loam(-) | Silt loam (-) | Sandy loam (-) | Clay(±) |
| **DISEASES** | | | | |
| Concentric-ring leaf spot | + | + | - | - |
| Anthracnose | + | + | + | - |
| White leaf spot | + | + | - | - |
| Bacterial blight | - | - | + | - |
| Superelongation | - | - | + | - |
| Brown leaf spot | - | - | + | ± |
| Cercospora leaf blight | - | - | + | + |
| **PESTS** | | | | |
| Mites: *Tetranychus* sp. | ± | | · | · |
| *Mononychellus* sp. | - | - | + | ± |
| Thrips | + | + | + | + |
| Scale insects | - | - | + | - |
| Stemborers | - | - | + | + |
| Lacebugs | - | - | - | + |

*+ = Severe damage
± = moderate damage

478
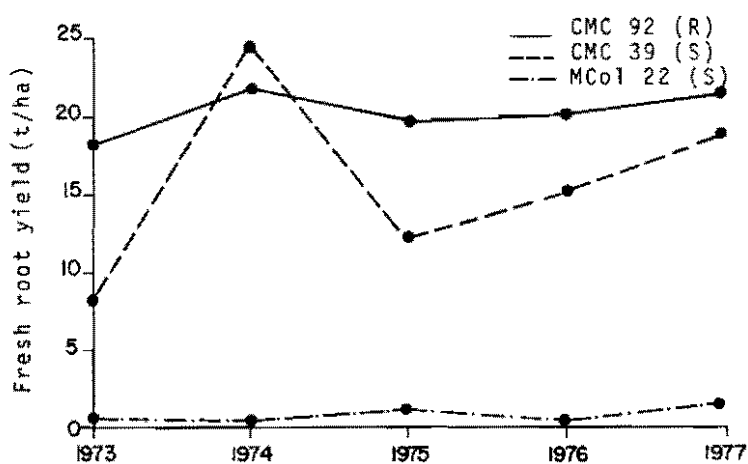
FIGURE 1.   YIELDS OF THREE VARIETIES IN POPAYAN OVER
            FIVE YEARS.
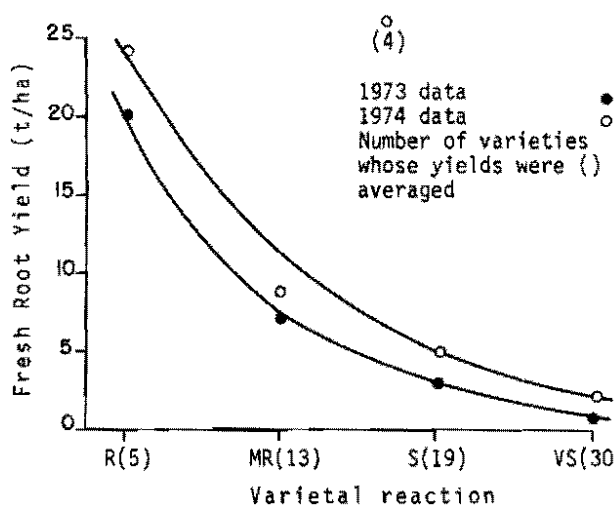
FIGURE 2. YIELD OF 67 VARIETIES AT POPAYAN IN RELATION TO THE NEGATIVE PRODUCTION FACTORS OF THIS ECOSYSTEM.

TABLE 3. FIELD EVALUATION IN THE POPAYAN ECOSYSTEM OF RESIS-
TANCE TO NEGATIVE PRODUCTION FACTORS (NPFs) IN RELA-
TION TO RAINFALL*

| Growing cycle | Reaction to NPFs[†] | | | Rainfall(mm) |
|---|---|---|---|---|
| | MCol 22 | CMC 39 | CMC 92 | |
| Year 1 | 4.9[‡] | 4.1 | 2.1 | 3119 |
| Year 2 | 3.5 | 2.0 | 1.5 | 2475 |
| Year 3 | 4.8 | 4.0 | 1.9 | 3103 |
| Year 4 | 5.0 | 3.9 | 1.9 | 3319 |
| Year 5 | 4.8 | 3.5 | 2.0 | 3365 |

\* Elevation 1760 m, mean temperature 18°C (4°C min, 20°C max).
Average data taken from 36 plants/variety over a 15-month
period.

1 = normal plant growth, no disease or pest attack.

2 = less than 30% leaf fall due to disease or pest attack
and/or climatic or edaphic factors, normal plant growth.

3 = up to 80% leaf fall and stem cankers or injuries due to
disease or pest attack and/or other climatic or edaphic
factors, slight stunting and yellowing.

4 = total defoliation, stem cankers, stunting and slight
dieback due to disease, pest and/or climatic or edaphic
factors.

5 = severe stunting or plant death due to disease, pest and
/or climatic or edaphic factors.

RECOMMENDED BREEDING STRATEGY

The foregoing considerations suggest that in order to breed
for varieties with a wide-type resistance, that is, to several
NPFs, the breeding programme should be decentralised. Several
representative ecosystems should be chosen as selection sites
where parental material and progeny should be evaluated for both
resistance and agronomic characters over several years. Hybridi-
sation for different ecosystems could be done on a centralised

TABLE 4.  YIELD (t/ha) OF DIFFERENT CLONES WITH
DIFFERENT REACTIONS TO NEGATIVE PRODUCTION
FACTORS (NPFs) EXISTING IN POPAYA, DARIEN
AND CIAT ECOSYSTEMS (SEE TABLE 2).

| Clone | Popayan | Darien | CIAT |
|---|---|---|---|
| CMC 92 | 22.3* | 26.6 | 8.2 |
| Morada | 16.5 | 18.3 | |
| MCol 80 | 13.7 | 15.3 | |
| MCol 235 | 14.5 | 11.5 | |
| MCol 230 | 11.3 | 10.3 | |
| MCol 307 | 6.5 | 6.7 | |
| CMC 39 | 8.6 | 8.8 | 13.0 |
| MCol 22 | 0.3 | 0.0 | 39.4 |
| MMex 59 | 0.9 | 2.4 | 33.1 |
| CMC 40 | 3.8 | 5.3 | 42.2 |
| CMC 84 | 1.0 | 4.0 | 40.3 |
| CMC 76 | 0.5 | 1.4 | 36.0 |
| MCol 113 | 5.0 | 2.5 | 26.8 |
| CMC 9 | 0.5 | 0.1 | 31.7 |
| MMex 23 | 1.0 | 1.0 | 34.3 |

*Data taken during 1974-1975 by the Agronomy and Pa-
thology sections of the Cassava Procuction Program
at CIAT (CIAT, 1976, 1977).

basis. Large quantities of vegetative material, selected at various sites, can be returned to a central location for hybridization by using the technique of Lozano and Wholey (1974) for production of CBB- and other disease-free planting material.

The progress of these improvement programmes would depend greatly on the genetics of the desired traits, the number of traits that have to be incorporated, the effectiveness of the evaluation techniques, and the number of progeny evaluated yearly. In some areas, for example, the local varieties may lack resistance to one factor but otherwise are well adapted with yield and quality. In this case the local variety should be improved by incorporating the resistance, crossing the local variety or varieties with a resistant one(s), and then selecting for resistance and the characteristics of the local variety. Several cycles would be required to accomplish this. An extreme case would be an area where there are no good local varieties, for example, Carimagua. In this case a large number of possible parents would have to be evaluated before beginning a recurrent population improvement programme (random corsses between parents, selection of progeny, random crosses between selections, etc).

These decentralised programmes would produce varieties with the necessary resistance for the ecosystem in question, in addition to stable, high yields. They would then be distributed to similar ecosystems and evaluated for several years. The validity of this distribution strategy is supported by the yield results of several varieties adapted to CIAT or Popayan and Darien, for example, and their respective yields at the other site (Table 4). With several regionally located breeding programmes, the unstable yields frequently exhibited by introduced high-yielding varieties bred in ecologically different areas could be avoided.

Lastly it should be kept in mind that cassava is in equilibrium with its pests and diseases at present, and great care should be taken not to upset this balance, thereby encouraging the development of pathogenic specialisation.


DISEASES OF CASSAVA


There are more than 50 cassava diseases reported in literature induced by fungal, bacterial, mycoplasmal, phytomonal and viral agents. Most of these pathological problems are located in the Americas and some of them have been introduced to Asia and Africa. However, even though some of these problems appear to have universal nature they only are severe under regional basis, according to the edaphic and climatic characteristics favoring the pathogen etiology.

483

# BACTERIAL DISEASES

Several bacterial species have been reported as cassava pathogens, but only *Xanthomonas campestris* pv. *manihotis*, causal agent of cassava bacterial blight (CBB), *X. c.* pv. cassavae, causal agent of the angular leaf spot, *Erwinia carotovora* pv. *carotovora*, causal agent of cassava stem rot, *Agrobacterium tumefasciens*, causal agent of cassava stem gall, and *Pseudomonas solanacearum*, causal agent of cassava bacterial root rot, have been identified as pathogens of cassava.

# BACTERIAL BLIGHT OF CASSAVA

Cassava bacterial blight (CBB) is the most important of several bacterial diseases of cassava reported (Costa, 1940; IITA, 1972; Lozano, 1972; Pereira and Zagatto, 1967). This disease has caused severe losses in several Latin American countries and Africa where epidemics have been recorded in the most important cassava growing areas. The diseases is now recognized as one of the most important factors limiting production in affected areas where, in wet seasons, it can result in complete loss of yield (Costa, 1940; Lozano, 1972; Lozano and Sequeira, 1974a; Pereira and Zagatto, 1967).

The disease was first recorded in Brazil in 1912 (Bondar 1912), but has since been reported in Colombia and Venezuela (Lozano, 1972; Lozano and Sequeira, 1974a and b), Nigeria (IITA, 1972), Zaire (Cock, personal information), and has been observed in several other countries of tropical America and Africa. It has only been reported in species and varieties of the genus *Manihot* (Amaral, 1942; Bondar, 1915; Burkholder, 1942).

## Symptoms

Symptoms of the disease are characterized by angular leaf spotting and blight, wilting, die-back, gum exudation, and stem and root vascular necrosis. This combination of symptoms is unique among the known diseases induced by plant pathogenic bacteria.

Primary symptoms, resulting from planting infected material, are wilting of the young germinated sprouts shortly followed by die-back. Secondary symptoms, resulting from secondary infections, are angular leaf spotting, followed by blight, defoliation, wilting and die-back. Leaf spots appear initially as watersoaked, angular areas, clearly distinguishable on the abaxial surface of the leaves (Fig.1). These spots become

484

FIGURE 1. CASSAVA LEAF LOBES SHOWING TYPICAL LEAF SPOTS
ON ABAXIAL SIDE

brown or dark-brown and sometimes, depending upon the suscep-
tibility of the cultivar, a yellow halo surrounding the spots
is clearly noticeable. Spots enlarge and coalesce, forming a
large necrotic blighted area. Necrosed areas spread through-
out the entire leaf and, as a result, leaves roll and dry.
These blighted leaves remain attached to the stem for a short
time but later fall (Fig.2). Leaf spots often exude a yellow-
ish, sticky gum that collects in droplets, mostly on the low-
er leaf surfaces and along veins or veinlets. Gum is also
characteristically exuded from cracks which often develop on
young infected stems and petioles. This gum then dries to
form a yellowish glistening scab.

Vacular strands of infected petioles and stems necrose
and appear as brown strings. Leaves fed by these necrosed
vascular strands wilt, and young stem tissues rot, particular-
ly surrounding the area where primary infection first occurs.
Rotting is faster in young (green) than in mature (green-brown)
stems, and old stem tissues remain apparently healthy. Rot-
ting of young stem tissues results in a characteristic die-
back symptom, which is restricted to the immature stem por-
tions of the plant (Fig.3).

Generally, roots of infected plants remain healthy. How-
ever, in some susceptible cultivars, swollen roots may show
dry, rooted spots around the necrosed vascular strands. This
rotting is usually restricted to the vascular tissues; the
other tissues of the root remain apparently healthy.

When infections occur on young immature plants, the aeri-
al portions may be completely destroyed. When this occurs
the plants usually produce new shoots from either above or
below ground portions of the stem base. These young shoots
are extremely susceptible and during rainy seasons rapidly
become infected, thus prolonging the epidemic.


Etiology

The causal agent was first named *Bacillus manihotis* Ar-
thaud-Berthet (Bondar, 1912) and later *Phytomonas manihotis*
(Arthaud-Berthet and Bondar) Viegas (Viegas, 1940). Drummond
and Hipolito (1940-41); however, found that some of the char-
acteristics of the bacterium they isolated from cassava were
different from those of the species originally described by
Bondar (1912). The species was later renamed by Burkholder
(1942) as *Phytomonas manihotis* and included as such as Bergey
's Manual (1948). Comparative studies of a new isolate with
strains from Burkholder and Drummond and Hipolito were made
by Amaral and Vasconcellos (1945). They concluded that the
three strains all belonged to *Ph. manihotis*. Later, Starr

486

FIGURE 2.   INFECTED CASSAVA PLANT SHOWING WILTING,
            NECROSED LEAVES STILL ATTACHED TO THE STEM.
            NOTE THAT YOUNG OR EMERGING SPROUTS ARE NOT
            YET AFFECTED BY THE PATHOGEN

(1946) changed the name to *Xanthomonas manihotis* (Arthaud-
Berthet) Starr (Bergey, 1957).  As a result of studies on mor-
phology, physiology, serology and phage susceptibility of the
bacterium isolated in Colombia, Brazil and Venezuela, Lozano
and Sequeira (CIAT, 1971; CIAT, 1972; Lozano, 1972; Lozano
and Sequeira, 1974a) concluded that they were sufficiently
different from *X. manihotis* to be considered a separate strain.
The reported (Lozano and Sequeira, 1974a) that the cassava
blight bacterium differed from *X. manihotis* in cell size, mo-
tility and flagellation, production of $H_2S$, utilization of ni-
trate, hydrolysis of starch, and in several serological rela-
tionships.  They also reported (Lozano and Sequeira, 1974a)
that a comparison with a type culture of *X. manihotis* reveal-
ed differences in pathogenicity, growth rate, serological
characteristics, and phage susceptibility.

    Recently, comparative studies among different American
and African isolates of this organism have revealed that they
possibly all belong to the same bacterial species although
there are differences in virulence and in a few physiological
characteristics (Sequeira, personal communication; Ikotun,
personal information).

    Lozano and Sequeira (1974a) described characteristics of
the causal or organism in detail and concluded that the cassa-
va blight bacterium should be considered as a strain of *X. ma-
nihotis*, but that its taxonomy needed further revision.

    The bacterium normally penetrates the host via stomatal
openings or through epidermal wounds (Lozano, 1972; Lozano
and Sequeira, 1974a and b).  Following penetration, the orga-
nism first invades and destroys the spongy mesophyll and then
enters the vascular tissues.  Once inside the vascular system,
the bacterial cells are able to more systemically throughout
the plant (Lozano, 1972; Lozano and Sequeira, 1974a).  Move-
ment into the stem and petioles is thought to take place pri-
marily through the xylem vessels (Amaral, 1942; Drummond and
Hipolito, 1940-41) and possibly through the phloem (Amaral,
1942; Pereira and Zagatto, 1967).  Movement through the pith
tissues has also been reported (Pereira and Zagatto, 1967).

    Infection by this organism is more common in, and is fre-
quently limited to, the young tissues of the plant where it
causes extensive breakdown of parenchymatous tissue s of sus-
ceptible cultivars.  In general, symptoms develop lignified
old stems the bacteria remain restricted to the vascular tis-
sues where they can survive for relatively long periods (Lo-
zano, unpublished).  It is thought that the lignified secon-
dary wall, and possibly also the middle lamella of mature ves-
sels, establish a barrier that the enzymatic system of this
bacterium is unable to overcome (Lozano, 1972; Lozano and Se-
queira, 1974a).

FIGURE 3.  SPROUTING CASSAVA PLANTS AFTER THE TOPS
WERE HEAVILY INFECTED BY CBB.  SOME OF
THE NEW SHOOTS THAT EMERGED REMAIN AP-
PARENTLY HEALTHY, BUT OTHERS ARE ALREADY
INFECTED SHOWING WILTING AND DIE-BACK.

During artificial inoculation experiments it has been found that at least 12 h at 100% relative humidity are required for bacterial establishment (Lozano, 1972). the influence of other environmental conditions on infection and disease development have not been reported.

## Epidemiology

The possibility that the pathogen spreads from one area to another by the use of infected cuttings was suggested by Amaral (1945) and demonstrated by Lozano (1972) and Lozano and Sequeira (1974b). Lozano (1972) and Lozano and Sequeira (1974 b) also have clearly demonstrated that the use of infected cuttings is largely responsible for the dissemination in localized areas. This accounts for the increased incidence of the disease in the rainy seasons as reported by Drummong and Hipolito (1940-41).

Some workers have suggested that the pathogen could be readily spread by soil movement during cultural operations or by the use of contaminated tools during prunning (Carneiro, 1940; Drummond and Hipolito, 1940-41; Drummond and Goncalves, 1953 and Goncalves, 1948). Although it is possible that bacteria can penetrate roots when plants are grown in heavily infested soils (Amaral and Vasconcellos, 1945; Drummond and Hipolito, 1940-41; Pereira and Zagatto, 1967) this means of disease spread is considered to be of minor inportance because of the short survival of this pathogen in the soil (Lozano, unpublished). Contaminated irrigation water is presently regarded as of minor importance. In contrast, however, the use of contaminated tools is probably an important means of bacterial dissemination (Lozano, 1972; Lozano and Sequeira, 1974a and b), especially considering the extensive amount of cutting that it is required during harvesting and preparing planting material.

As the bacteria enter plants through wounds, the movement of man, animals, and insects through a crop is also likely to spread the disease, however little evidence is available to demonstrate this. Insects have been suggested as possible agents for dissemination (Amaral, 1945), and their possible role in disseminating bacteria has recently been demonstrated at CIAT. Controlled experiments, using insecticides, have shown that insect dissemination could be as high as 10% of the total infection in a plot (Ikotun, Imperial College, London, personal communication). However, studies on dissemination from an inoculum source to plants located at different distances (CIAT, 1972); Lozano, 1972; Lozano and Sequeira, 1974b).

During dry periods disease development slows, little bac-

490

teria containing gum is exuded, and hence spread of the disease is halted. The bacteria, however, remain viable in the plant and become active during subsequent rainy periods.


## Control

Delay in spread of the disease by prunning most of the above ground portion of infected plants has been reported (CIAT, 1972; Lozano, 1972; Lozano and Sequeira, 1974b). However, the success of this method depends on the susceptibility of the cultivar and the interval between initial infection and prunning. This method is most successful with resistant and moderately resistant cultivars which are lightly infected. It has little effect with severely infected susceptible cultivars, as the new shoots rapidly become reinfected, necessitating regular and extensive prunning. Such extensive prunning almost certainly affects the quality, as well as the yield, of roots. It must also be emphasized that although this method may be used to slow the spread of an epidemic in certain instances, it will never give complete control.

For the complete control of this disease, exclusion of the pathogen by the use of clean 'seed' has been suggested (Carneiro, 1940; Drummond and Hipolito, 1940-41 and Goncalves, 1948). A successful means of producing bacteria-free 'seed' has been developed by Lozano and Wholey (unpublished). The method involves the rooting of bacteria-free stem tips of infected or non-infected plants and can be used to clean infected cultivars or stocks thus providing certified bacteria free cassava 'seed'. Physical treatments, such as exposure to hot air, hot water, microwaves, and ultraviolet light, for the inactivation of bacteria in infected planting material have so far given negative results (Prada, Zarate and Lozano, unpublished).

The use of crop rotation has also been suggested as a means of control (Carneiro, 1940). Lozano (unpublished) suggested that if all infected plant debris is removed and destroyed by burning, and interval of six months between successive cassava crops is probably sufficient to prevent carry over of the disease in the soil.

Control by the use of cultivars resistant to bacteria was first suggested by Goncalves (1948), and numerous field resistant cultivars have since been reported (Carneiro, 1940; Drummond and Goncalves, 1953; Pereira and Zagatto, 1967). These field observations have been confirmed in greenhouse studies conducted by Lozano and Sequeira (1974b). Their studies also revealed that three possible types of resistance exist in different cultivars: one type apparently limits penetration, another type limits systemic invasion and establishment, and the third type is apparently based on a hypersensi-

tive response of the host (Lozano and Sequeira, 1964b).

A combination of the use of resistant varieties and the use of bacterial free planting material appear to be the most promising means of controlling this important disease.

## *ERWINIA CAROTOVORA* VAR. *CAROTOVORA*, CAUSAL AGENT OF BACTERIAL STEM ROT OF CASSAVA: ETIOLOGY, EPIDEMIOLOGY AND CONTROL.

At least four bacterial species have been reported as cassava pathogens: *Xanthomonas manihotis* (Arthaud-Berthet and Bondar) Starr, causal agent of cassava bacterial blight, which is the most common, widespread and important bacterial patho-gen of the crop (Lozano, 1975; Terry, 1978); *X cassavae* Wiehe and Dowson, which induces leaf spotting (Dowson, 1957; Wiehe and Dowson, 1953); *Agrobacterium* sp., recently described as the causal agent of cassava bacterial stem gall (CIAT, 1978); and *Erwinia cassavae* (Hansford) Burkholder, which causes leaf spot-ting, defoliation and stem and petiole necrosis (Hansford, 1938). This species has been included in the *E. herbicola* group (Bucha-nan and Gibbons, 1974). *Pseudomonas solanacearum* was also re-ported as a pathogen of cassava (Bradbury, 1975), but our recent investigations indicate that cassava is not affected by this bacterium. The existence of *E. cassavae* was questioned by Wiehe and Dowson (1953) because the reported symptoms are generally similar to those of *X. cassavae* (Wiehe and Dowson, 1953; Dowson, 1957); they are almost identical to those induced by *X. manihotis* (Lozano, 1975; Terry, 1978).

During the past four years, a bacterial disease associat-ed with damage induced by *Anastrepha* spp. (cassava fruitfly) has been observed in a cassava-growing area of Colombia (Caice-donia). The symptomatology is different from all other bacteri-al diseases of cassava reported thus far (Lozano *et al*, 1976; Mattas, 1977; CIAT, 1978). On the basis of etiological studies this bacterial pathogen showed a close similarly to *E. carotova* var. *carotovora*. Investigations on this pathogen and the dis-ease that it causes are reported here, as well as observations on epidemiological factors influencing the disease and measures for its control.

### Symptoms

The cassava bacterial stem rot disease is characterised by partial or total wilting of young shoots or branches of in-fected plants, followed by tip collapse and dieback or canker formation on lignified stem portions. These symptoms initiate from damage induced by *Anastrepha* spp. larvae boring in the stem.

The larvae bore-up or downward in the stem producing extensive tunnels; this wounding provides an entrance for the bacterial pathogen which initiates severe stem rotting. The insect entrance is usually masked by an exudate of white latex from the larval tunnel. During the wet season bacterial infection after insect damage is initially characterised by a dark brown epidermal and cortical discolouration, followed by total stem tissue maceration in 3-4 days (Fig.1). When the pathogen invades, all the young stem tissues are degraded. If the stem is lignified, only the pith area is invaded, appearing as a yellow to dark brown necrosis. Oviposition or initial insect damage is usually in unlignified stem portions: bacterial invasion and stem necrosis is limited and internally restricted to the pith (Fig.2). External cankers of different sizes form, causing stem deformation.

As a consequence of bacterial/insect infection, plants become stunted and tend to sprout from below diseases stem portions. New sprouts can be reinfested by insects and infected by the bacterial pathogen a few days after their emergence, depending on insect population and climatic conditions; during the dry seasons no bacterial infection is noticeable and plants can recover fully even when insect infestation is present (Lozano *et al*, 1976; CIAT, 1977; Bellotti and Schoonhoven, 1978).

Plants derived from infected cuttings may be generally weak and with few swollen roots that are sometimes decayed. When cuttings are heavily affected, roots may fail to develop properly and plants may die during the first month (Lozano *et al*, 1977; Bellotti and Pena, 1978).

The above symptoms induced the cassava stem rot bacterium (CSRB) and its dissemination are different from those reported for *E. cassavae* (Hansford, 1938) or any other cassava bacterial pathogen (Lozano *et al*, 1976; CIAT, 1978). No leaf spotting, defoliation or gum exudation are induced by CSRB.

Etiology

Cultural Characteristics

On TZC medium (Kelman, 1954), after 48 h incubation at 25 °C, CSRB develops medium size, circular, convex, undulate to coralloid, croos-hatched colonies, when examined by oblique lighting a with a small diffuse pink centre surrounded by a pale blue halo. On a pectate medium colonies are sunken due to liquefaction of the pectate.

The bacterium grows in ordinary culture media, does not produce pigments, but reduces tetrazolium salts. On sugar-contain-

493

FIGURE 1.  YOUNG UNLIGNIFIED TOPS WILTED
BY THE STEM ROT BACTERIUM 3
TO 4 DAYS AFTER BACTERIAL PE-
NETRATION.



FIGURE 2.  DIFFERENT DEGREES OF INSECT
/BACTERIUM DAMAGE IN PARTIAL-
LY LIGNIFIED STEMS

ing media, colonies are medium size, circular, convex, undula-
te to coralloid, but not mucoid.

The bacterial pathogen is a slender Gram-negative rod.  Mea-
surements from electron photomicrographs of 24 h-old cells grown
in yeast extract (1%)-dextrose (1%) liquid medium, indicate an
average size of 2.4 μm (range: 1.6-2.9 μm) by 1.2 μm (range 0.8-
1.6 μm).  The cells are motile with 4-8 peritrichous flagella.
Cells are not encapsulated, do not form spores, and are single
or form short chains of 2-3 cells in 48 h-old cultures.


Artificial Inoculations

Bacterial infection by artificial inoculation occurs only
when stems or roots are wounded.  No infection was obtained when
plants were inoculated by spraying or by the leaf clipping method
using scissors dipped in inoculum.  In plants inoculated by stem
puncturing with infested needles, soft rotting appeared around
the point of inoculation 2-3 days later.  Afterwards, bacterial
invasion increased, inducing total soft rotting of the young un-
lignified stem portions.  In partially and fully lignified stems,
bacterial invasion is restricted to the pith.  Puncture inocula-
tions on lignified stems induce very restricted bacterial inva-
sion and rotting.  The pith becomes necrotic, showing yellow to
dark brown colouration, but invasion is very localised (CIAT,
1977; Mattos, 1977; Bellotti and Pena, 1978).

Roots decayed following inoculation only if roots were
wounded; young stem or root infection was characterised by a
pungent odour.  One-month-old infected plants were killed 1-2
months after inoculation when 60% or more of the root system
was infected.

There were no differences in virulences among isolates or
varietal reaction when plants were inoculated by either stem
puncture or root wounding (Mattos, 1977).

In nature, bacteria infection has been observed exclusive-
ly when stems are damaged by *Anastrepha* spp.  However, not all
insect-attacked plants show bacterial infection.


Bacterial and Physiological Characteristics

The mass doubling time of this organism is Kelman's liquid
medium (Kelman, 1954) without tetrazolium salt at 28°C was 40
min.  the optimum temperature for growth was between 24 and 28
°C.  The bacterium did not produce visible growth at 8 or 38°C
(Mattos, 1977).

Results of biochemical and physiological tests with four
isolates of this pathogen were similar in all characteristics

(Table 1). Most biochemical, physiological and cultural charac-
teristics of CSBR were also similar to those of *E. carotovora*
(Table 2). It differed from *E. herbicola* in pectate degrada-
tion and production of phenylalanine diaminase and yellow pig-
ments; *E. chrysanthemi* in indole, lecithinase and phosphatase
production, erythromycin sensitivity and growth in 5% NaCl; and
*E. carotovora* var. *atroseptica* in growth at 36°C and reducing
compounds from sucrose (Table 2). Although dulcitol and glyce-
rol were slightly acidified after four days' incubation (Table
3), CSBR's acid production from organic compounds was most si-
milar to *E. carotovora* var. *carotovora*.

Moreover, CSBR was also able to utilise DL-serine, L-leu-
cine, glycine, D-tryptophan, DL-threonine, DL-methionine, L-pro-
line and L-histidine. It grew poorly on basal medium plus DL-
alanine, DL-valine, L-tyrosine, DL-phenylalanine or OH-L-hydro-
xyproline as sources of carbon and nitrogen. It did not utili-
se L(+) arginine, lysine or ornithine. Among organic acid com-
pounds, citrate was utilised, but the following fatty and orga-
nic acids were not:pelargonate, N-capryllate, N-caprate, isova-
lerate, isobutyrate, adipate, glutamate, pimelate, itaconate,
L-malate and thiosulfate.

CSRB was sensitive to sulfadiazine, tetracycline, chloram-
phenicol, sulfathiazol, aureomycin and terramycin, but resistant
to vancomycin, novobiocin, erythromycin, bacitracin, penicillin,
polymyxin, streptomycin and lincomycin (Mattos, 1977).

The foregoing biochemical, physiological and cultural cha-
racteristics (Table 2 and 3) indicate that CSRB is closely re-
lated to the *E. carotovora* group and is indistinguishable from
*E. carotovora* var. *carotovora*. On the other hand, a comparison
of *E. cassavae* (Hansford, 1938) with CSRB (Table 4) indicates
that they are different species.

Since, 1, symptoms reported induced by *E. cassavae* are dif-
ferent from those of CSRB (Table 4) but similar to *X. manihotis*
(Lozano, 1975; Terry, 1978); 2. it was found that the isolate
reported pathogenic by Hansford was not pathogenic but closely
related to *E. lathyri*, a common and ubiquitous saprophyte cons-
tantly associated with diseased plant tissues (particularly
leaves)(Wiehe and Dowson, 1953); and 3. no *Erwinia* species has
been isolated from cassava since 1938 when *E. cassavae* was re-
ported, and no type culture of this organism is available, the
validity of the designation *E. cassavae* is in question. Thus
cassava is presently reported as a host of *E. carotovora* var.
*carotovora*.

TABLE 1. BIOCHEMICAL, PHYSIOLOGICAL AND CULTURAL TESTS ON FOUR ISOLATES OF CASSAVA STEM ROT BACTERIUM (CSRB)*

| Test | Reaction | Method (Reference) |
|---|---|---|
| Growth factors required | Negative | Dye, 1968 |
| H₂S from cysteine | Positive | Dye, 1968; Harrigan and McCause, 1966 |
| Urease | Negative | Dye, 1968 |
| Growth at 36°C | Positive | Lozano and Sequeira, 1974 |
| Gluconate oxidation | Negative | Buchanan and Gibbons, 1974 |
| Sucrose, reducing compounds | Negative | Buchanan and Gibbons, 1974 |
| Pectate degradation | Positive | Blair *et al*, 1970; Cuppels and Kelman, 1974 |
| Mucoid growth | Negative | Buchanan and Gibbons 1974 |
| Motility | Positive | Lozano & Sequeira, 1974 |
| Nitrate reduction | Positive | Difco, 1969; Dye, 1968 |
| Gelatin liquefaction | Positive | Dye, 1968; Misaghi and Grogan, 1969; Burnette *et al*, 1957 |
| Phenylalanine deaminase | Negative | Blair *et al*, 1970; Dye, 1968 |
| Indole | Negative | Dye, 1968 |
| Casein hydrolysis | Positive | Dye, 1968 |
| Blue pigment | Negative | Buchanan and Gibbons, 1974 |
| Yellow pigment | Negative | Buchanan and Gibbons, 1974 |
| Maximum growth temperature | 38°C | Lozano and Sequeira, 1974 |
| Growth in 5% NaCl | Positive | Dye, 1968 |
| Lecithinase | Negative | Difco, 1969; Dye, 1968 |
| Phosphatase | Negative | Blair *et al*, 1970; Burnette *et al*, 1957 |
| Starch hydrolysis | Negative | Burnette *et al*, 1957 |
| Reduction of litmus milk | Positive | Burnette *et al*, 1957 |
| Oxidase | Negative | Blair *et al* 1970; Misaghi and Grogan, 1960 |
| Lipase | Positive | Sierra, 1957 |
| Soft rot of potatoes, carrots and cassava roots | Positive | Lozano and Sequira, 1974 |
| Hypersensitive reaction in tobacco leaves | Negative | Klement, 1964 |
| Methyl red and Voges-Proskauer reactions | Positive | Blair *et al*, 1970; Burnette *et al*, 1957 |
| Nitrite from nitrate | Positive | Blair *et al*, 1970; Harrigan and McCause, 1966 |
| NH₄ from nitrate | | |

* Lozano *et al*, 1977; personal data

TABLE 2. COMPARATIVE BIOCHEMICAL, PHYSIOLOGICAL AND CULTURAL CHARACTERS OF DIFFERENT *Erwinia*
SPECIES AND VARIETIES AND THE CAUSAL AGENT OF CASSAVA STEM ROT BACTERIUM (CSRB).

| Character | E. herbicola var. herbicola | E. chrysanthemi | E. carotovora var. atroseptica | E. carotovora var. carotovora | CSRB |
|---|---|---|---|---|---|
| Growth at 36°C | +** | + | - | + | + |
| Gluconate oxidation | d | - | - | - | - |
| Sucrose, reducing compounds | d | d | + | - | - |
| Pectate degradation | - | + | + | + | + |
| Mucoid growth | d | d | - | d | - |
| Phenylalanine deaminase | + | - | - | - | - |
| Indole | - | + | - | - | - |
| Casein hydrolysis | - | d | d | + | + |
| Yellow pigment | + | - | - | - | - |
| Maximum growth temperature | 37-40 | 37-40 | 35 | 37-40 | 38 |
| Growth in 5% NaCl | | - | + | - | + |
| Lecithinase | | + | - | - | - |
| Phosphatase | | + | - | - | - |
| Sensitive to erythromycin(50μ) | | + | - | - | - |

* Source: Bergey's Manual, 8th edition (Buchanan and Gibbons, 1974).
** + = Positive reaction
   - = Negative reaction
   d = 21 to 79% of strains were positive

498

TABLE 3.   ACID PRODUCTION FROM ORGANIC COMPOUNDS BY DIFFERENT *ERWINIA* SPECIES AND VARIETIES AND THE CAUSAL AGENT OF CASSAVA STEM ROT BACTERIUM (CSRB).

| Compound | *E. herbicola* var. *herbicola**  | *E. chrysanthemi** | *E. ????* var. *atroseptica** | *E. ????* var. *carotovora** | CSRB |
|---|---|---|---|---|---|
| Arabinose | +*** | + | + | + | + |
| Mannitol | + | + | + | + | + |
| Salicin | d | + | + | + | + |
| Xylose | + | + | + | + | ± |
| Raffinose | d | d | + | + | + |
| Dulcitol | - | - | - | - | ± |
| Inositol | - | - | - | d | ± |
| Lactose | d | - | + | + | + |
| Melizitose | - | - | - | - | - |
| Melibiose | - | d | + | + | + |
| Maltose | + | - | + | d | + |
| Adonitol | - | - | - | - | - |
| Cellobiose | - | + | + | + | + |
| Dextrin | + | - | - | - | - |
| Esculin | d | + | + | + | + |
| Glycerol | - | - | - | - | ± |
| Mannose | + | + | + | + | + |
| Rhamnose | + | + | + | + | + |
| Ribose | + | + | + | + | + |
| Sorbitol | + | + | + | + | ± |

* Source:  Bergey's Manual, 8th edition (Buchanan and Gibbons, 1974).
*** + = Positive reaction
  - = Negative reaction
  ± = Positive reaction after four days incubated
  d = 21 to 79% of strains were positive

TABLE 4.    CHARACTERISTICS OF *E. CASSAVAE* (*E. HERBICOLA*)
AND DISEASE SYMPTOMS COMPARED WITH THOSE OF
CASSAVA STEM ROT BACTERIUM (CSRB).

| Feature | *E. cassavae* | CSRB |
|---|---|---|
| Gram stain | -** | - |
| Encapsulation | - | - |
| Flagellation | peritrichous | peritrichous |
| Gelatinase | + | + |
| Litmus milk | alkalinized | acidified |
| Nitrate reduction | + | + |
| Yellow pigment | + | - |
| Acid formed with: | | |
| glucose | + | + |
| sucrose | + | + |
| maltose | + | + |
| lactose | - | + |
| glycerol | + | ± |
| Symptoms: | | |
| leaf spotting | + | - |
| defoliation | + | - |
| stem rot | + | + |

\*   Source: Hansford (1938)

\*\* + = positive reaction
   - = negative reaction
   ± = positive reaction after four days' incubation


The Insect Vectors

     The cassava fruit and stem flies are Diptera(Tephritidae)
pest of cassava found only in the Americas.   Two species of
*Anastrepha* have been identified attacking cassava in Colombia:
*A. pickeli*, found in the Cauca Valley (1000 m), and *A. manihoti*,
found in the coffee-growing regions (1200 m).   Bacterial asso-

500

ciation with both insect species has been found (Bellotti and pena, 1978; Bellotti and Schoonhoven, 1978). This fly was originally reported attacking the fruit of cassava where it causes no economic losses (Bellotti and Pena, 1978).

The yellow- to tan-coloured female inserts the eff in the succulent part of the stem, about 10-20 cm from the tip, so that about one third of the egg with a slender white rot protrudes. After hatching, the white to yellow larvae bore up or downwards in the stem pith region. Numerous eggs may be deposited in one stem and several larvae may be found per stem. Mature larvae leave the stem or fruit and pupate on the gound. Adults emerge in about 17 days (Lozano *et al*, 1976; Bellotti and Pena, 1978; Bellotti and Schoonhoven, 1978).

Epidemiology

Dissemination of the Pathogen

Studies indicate that the pathogen is disseminated by fruit and stem flies (*Anastrepha* spp.), which also provide the wounds for bacterial penetration into the host (CIAT, 1977; Mattos, 1977). The pathogen was isolated from a small percentage of adults (1-2%) collected from plantations in which infected cassava plants were found, whereas a high percentage of larvae collected from infected stems were infested (90%). CSRB was isolated only on the body surface of adults, whereas it would found within the larvae when there was an insect/bacterium association (CIAT, 1977; Nattos, 1977). These results suggest that the adult insects are responsible for the dissemination of the pathogen to cassava plantations from outside inoculum sources because they do not feed on cassava, and that the larvae provide the entry for the pathogen and can also disseminate it throughout the stem tissues after the bacterium has been established in the host.

The decayed tissue in the stem does not appear to be a favourable environment for the larvae; inspections of rotting stems showed 40% larval mortality (Bellotti and Pena, 1978). This appears to be due to either toxic compounds produced by the pathogen or to pH changes of the rotted tissues due to metabolic by-products released during the bacterial growth. This unfavorable environment for the vector may also indicate that increased populations of these insects may result from infestations of the cassava fruit or alternate hosts rather than from cassava stem infestations. The fruit of several other plant species commonly found in areas of high fruitfly populations have been examined, but no additional hosts to these species have been identified yet (Bellotti and Pena, 1978).

501

Epiphytic Survival of the Pathogen

It was found that the pathogen was able to survive epiphy-
tically for 132 h on the leaf and stem epidermis when relative
humidity was near 100% and that its concentration increased
more than 100-fold (Fig.3)(CIAT, 1977; Mattos, 1977).  When
CSRB-free larvae were fed with CSRB-contaminated diet for 30 min,
the pathogen was isolated for 72 h after larval feeding, but
bacterial numbers decreased with time (Mattos, 1977).  Data on
survival ability of this pathogen is soil, cassava debris or
decayed fruits of different plant species are not available.
However, present data suggest that once the insect infests the
epidermis of the plants with the pathogen, this may survive epi-
phytically and later penetrate the host when insect larvae bore
in the stems.  This was demonstrated by controlled inoculation
trials:when simulating insect damage, stems of two-month-old
plants were punctured with sterile needles, and subjected to 36
 h of spray inoculation (bacterial concentration = 2.3 x $10^9$
cell/ml), plants became infected if they were kept in a mist
chamber.  Spray-inoculated unpunctured plants did not become in-
fected in the same environment.  This may also indicate that in
nature the bacterium amy reach the host entry (holes made by the
insect) by the washing effect of rain.


Disease Occurrence and Severity

The disease has been observed and the pathogen isolated in
areas with an average temperature of 22-25°C, altitude of 1000-
1200 m and raingall of 1000-2200 mm/year, but no survey to de-
tect the disease in areas with other climatic conditions has
been done.  In infected areas, disease incidence (infected
plants/total plant population/farm) and severity (degree of
stem rotting) are high during the rainy season (Table 5)(Mattos,
1977).  During the dry season, symptoms of the disease are not
externally noticeable, but the pathogen is found infecting the
pith.

With artificially inoculated one-month-old plants, disease
severity was greater at 100% than at 70% relative humidity dur-
ing incubation (Fig.4)(CIAT, 1977; Mattos, 1977).  When two-
month-old plants were stem inoculated and incubated at 100% r.h.
for 72 h two-thirds of the stems were rotted; when inoculated
plants were incubated at 70% r.h. rotting only appeared around
1-2 cm of the inoculated point after 96 h of inoculation (Mattos,
1977).  These indicate that the pathogen requires a high rela-
tive humidity for invasion and subsequent stem damage.  This re-
lates to observations on disease occurrence and severity under
field conditions.

It has also been found that bacterial infection is much
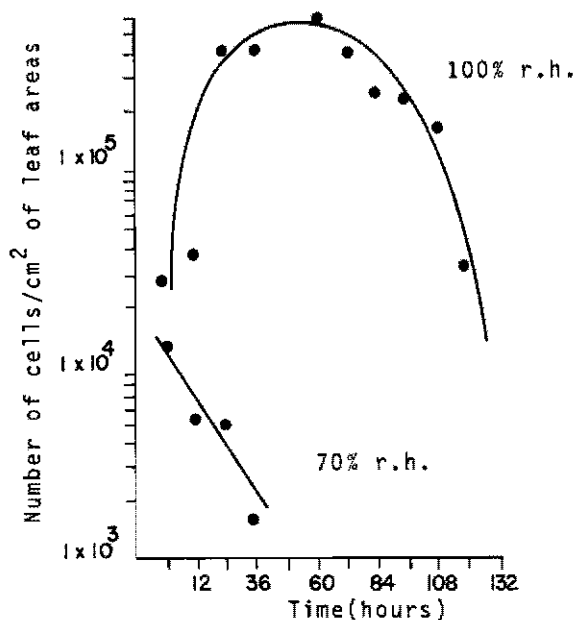more severe in the young stem tissues, where CSRB causes com-

FIGURE 3. CSRB SURVIVAL ON LEAF SURFACE OF CASSAVA
VARIETY CHIROZA AT TWO LEVELS OF RELATIVE
HUMIDITY (MATTOS, 1977). PLANTS WERE MAIN-
TAINED IN A CONTROLLED GROWTH CHAMBER.
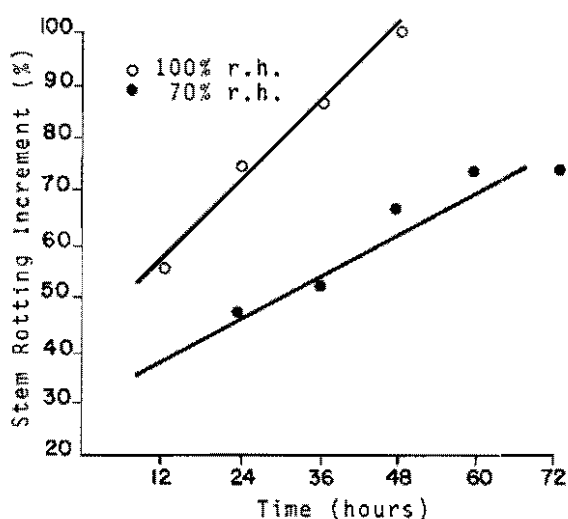
FIGURE 4.   BACTERIAL STEM ROT IN RELATION TO
            RELATIVE HUMIDITY.   PLANTS WERE
            MAINTAINED IN A CONTROLLED GROWTH
            CHAMBER

TABLE 5.  DISEASE INCIDENCE (AVERAGE NUMBER OF AFFECTED PLANTS
/PLANT POPULATION) AND SEVERITY (GRADE OF STEM ROT-
TING) ON THREE FARMS (*MANIHOT ESCULENTA* VAR. *CHIROZA*)
IN THE CAICEDONIA AREA DURING RAINY (MAY, JUNE AND
FIRST HALF OF JULY) AND DRY (SECOND HALF OF JULY, AU-
GUST AND SEPTEMBER) SEASONS*.

| Month (1975) | Plant age (months) | Affected plants (%) | Number of plants in each disease grade** | | | | |
|---|---|---|---|---|---|---|---|
| | | | 0 | 1 | 2 | 3 | 4 |
| May | 2 | 1 | 99 | 0 | 0 | 1 | 0 |
| June | 3 | 20 | 80 | 8 | 10 | 2 | 0 |
| July | 4 | 13 | 87 | 7 | 6 | 0 | 0 |
| August | 5 | 8 | 92 | 1 | 7 | 0 | 0 |
| September | 6 | 0 | 100 | 0 | 0 | 0 | 0 |

*    Mattos, 1977
**   Disease grade: 0 = no symtom
                    1 = 1-2 cm rotted area around the insect
                        hole
                    2 = rotting on 1/3 of the green stem por-
                        tion
                    3 = rotting of 2/3 of the green stem por-
                        tion
                    4 = all green stem portion affected

plete tissue maceration when relative humidity is near satura-
tion (CIAT, 1977; Mattos, 1977); Under field conditions, the
disease is present on plants of all ages if they have been at-
tacked by the insect, but the damage is much more severe when
this insect/bacterium association takes place in young unligni-
fied sprouts or branches during the rainy seasons.  Younger (1-2
months old) infected plants can be more severely damaged than
older ones; these younger affected plants suffer sttunting and
sprout much more than older affected plants.

    Insect/bacterium stem damage reduces the quality of the
affected stem portions when used for planting.  This damage
shows different levels of infestation/infection, depending on

the degree of insect/bacterial attack which goes from a brown
discolouration in the pith area to severe rotting of pith and
tunnel throughout pith area (Lozano *et al*, 1977; Bellotti and
Pena, 1978; CIAT, 1978).


Possible Disease Cycle

Insect adults generally live and feed on fermenting organic
debris, common in the cassava-growing areas where the vectors
and the disease are endemic. Thus it is possible that in these
locations the adult flies become infested and later spread the
pathogen on the surface of the plant when they visit cassava
plantations to oviposit in the stem. When the larva emerges,
it bores through the stem causing a wound where the pathogen,
which may have survived epiphytically on the plant surgace, pe-
netrates into the stem tissues of the host carried by the wash-
ing rain. This is corroborated in nature by the presence of
plants attacked by both insects and pathogen mostly during the
rainy periods and by the fact that the association insect/bacte-
rium is almost nil during the dry periods even though the insect
and its damage are present. The effect of the bacterial pathogen
in the root system of cassava in infected soils is unknown, but
soft rotting of roots has been observed in infected plantations.


Insect/Disease Losses

The effect of insect/disease losses on cassava production
is not well known. In one study 100 plants damaged by fruit-
flies were harvested, root yield recorded and compared to the
yield of 100 undamaged plants. There was a 5% reduction in
root yield of the damaged plants. Since affected plants were
stunted and may have been shaded by their healthy neighbours,
yield losses may have been overestimated (Bellotti and Pena,
1978; CIAT, 1978).

It is also suspected that rotting may cause a reduction in
rotting when infected stems are used as planting material and
that yield from damaged planting material may be reduced.

Results in farmer's field experiments showed a decrease in
cutting germination ranging from 5-16%, according to cutting
damage. Damaged cuttings showed an average of 9% reduction in
rooting compared to non-damaged ones. Studies on the effecc of
damaged cuttings on root yield showed a 17.4% yield reduction
as compared to undamaged cuttings and yield losses ranged from
4.2-33.1%, according to damage intensity (Table 6)(Bellotti and
Pena, 1978).

TABLE 6.   THE EFFECT OF DAMAGE CAUSED BY THE FRUITFLY *ANASTRE-*
*PHA MANIHOTI* AND CSRN ON ROOTING OF CASSAVA CUTTINGS
AND PLANT YIELD*

| Damage grade** | Rooting (%) | Yield (Kg/ha)/farm No. | | | | Yield reduction (%) |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | |
| 0 | 90.3 | 38.9 | 41.0 | 40.7 | 40.2 | |
| 1 | 85.7 | 32.9 | 38.1 | 44.5 | 38.5 | 4.2 |
| 2 | 83.7 | 26.3 | 39.2 | 38.3 | 34.6 | 13.9 |
| 3 | 82.7 | 20.0 | 26.5 | 34.2 | 26.9 | 33.1 |
| 4 | 74.0 | 29.2 | 31.6 | 37.7 | 32.9 | 18.3 |

\*    Bellotti and Pena, 1978
\*\*  Cutting damage grade: 0 = no damage
                           1 = a brown discolouration in the pith
                               areas
                           2 = discolouration and rotting of a
                               pith at both ends of cuttings
                           3 = severe rotting of pith
                           4 = severe rotting of pith and tunnel-
                               ing throughout pith area.

Control

    No significant differences in the degree of stem rotting
were found among stem puncture-inoculated cultivars (CIAT, 1977).
Consequently, it appears that the best way to control this dis-
ease is to identify cultivars resistant to the insect or to con-
trol the insects directly.  Nevertheless, since yield is reduc-
ed when infected cuttings are used for propagation, the careful
selection of clean planting material is very important.  Simi-
larly, the insect/bacterium can be controlled by cutting, col-
lecting and burning infected cassava tops and stem debris, as
well as decayed fermenting fruits of plant species where the
adult insects also feed (guavas, oranges, etc).

    Studies related to insect control have shown that the insects
can be controlled by:

    1. Insecticides.-  Fenthion gave 100% larval control 8 days

after applications, and was still 90-100% effective after 16 days. It should be noted that although larvae were controlled in the stem, the insecticidal spray did not prevent infestation and subsequent bacterial rotting of stem tissues (Bellotti and pena, 1978; Lozano *et al*, 1976).

2.Insecticides plus attractants.- After evaluating three bait combinations (yeast, molasses and yeast plus molasses), it was found that yeast alone (Table 7) was the most effective, resulting in more than double the adult mortality than when the insecticide (EPN) was used alone. the addition of molasses had no effect on mortality; and when combined with yeast, mortality was greatly reduced (Bellotti and Pena, 1978; CIAT, 1978).

3.Attractans.- Several attractans were compared for effectiveness in fruitfly capture using a McPhail trap. Hydrolysed mayze gave nearly three times greater capture than any of other attractants (Bellotti and Pena, 1978; CIAT, 1978). Hydrolysed mayze was also nearly twice as effective as the most successful of 100 synthethic attractants obtained from the USDA (Bellotti and Pena, 1978; CIAT, 1978).

4.The use of varieties resistant to the insect appears to be the most promising control method. Preliminary screening indicates that resistant varieties to these pests exists (CIAT, 1978).

Since yield losses due to the direct attack by the insect /pathogen have not been shown, insecticidal control is questionable. The use of systemic insecticides (fenthion) does not prevent entrance of the larvae and consequently invarions by the pathogen occurs. Insecticidal control of adults appears impractical since even if flies are controlled in the field, subsequent attacks could occur due to the fly's mobility. In addition, insecticidal applications would destroy the natural enemies of the other pests, especially the cassava hornworm (*Erynnyis ello*), consequently causing severe outbreaks (CIAT, 1977; Bellotti and Schoonhoven, 1978; CIAT, 1978).

TABLE 7. YEAST AND MOLASSES AS BAITS MIXED WITH THE INSECTICIDE EPN FOR CONTROL OF CASSAVA FRUITFLY (*ANASTREPHA* SPP.) ADULTS IN FIELD TRIALS**

| Treatment (rate) | | Adult mortality/replication | | | | Av. adult mortality |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | |
| EPN (12 ml/12/$H_2O$) | | 25 | 42 | 43 | 3 | 28.3 a** |
| EPN (12 ml/12/$H_2O$) | + yeast (0.5 Kg) | 71 | 103 | 41 | 17 | 58.0 b |
| EPN (12 ml/12/$H_2O$) | + molasses (0.5 Kg) | 49 | 49 | 18 | 14 | 32.5 a |
| EPN (12 ml/12/$H_2O$) | + yeast (0.5 Kg) + molasses (0.5 $l$) | 34 | 79 | 24 | 3 | 35.0 a |

*   Bellotti and Pena, 1978; CIAT, 1978

**  Average followed by different letters are significantly different at the 0.05 level

# BACTERIAL LEAF SPOT OF CASSAVA

Wihe and Dowson (1953) reported a bacterial disease of cassava in Malawi (Nyasaland). This disease is characterised by leaf spots which are at first yellow and circular. As these spots enlarge, they become angular with a brown centre and a broad yellow halo. The leaf veins radiating from the margins of these spots become dark brown but the leaves are shed before the petioles become infected thus providing stem infection. Under humid conditions a sticky liquid containing bacteria is exuded from lower leaf surfaces and rain splashing of this exudate spreads the disease. The causal agent was named *Xanthomonas cassavae* sp. n. which is a gram-negative rod mobile by means of pola flagellum. Colonies on nutrient agar and glucose agar are pale yellow, confluent, and viscous. It forms acid from sucrose, small amounts of acid from dextrose and maltose, and no acid from lactose, salicin, glycerol, or mannitol. It produces hydrogen sulphide from peptone and nitrites from nitrates (Wihe and Dowson, 1953; Dowson, 1957).

# BACTERIAL STEM GALL OF CASSAVA

This disease was recently reported incucing stem gall symptoms on scathered plants of a plantation at Colombia. It has been also observed in Brasil, but its incicence is low and restricted to a few clones. It is induced by *Agrobacterium tumefasciens*, bacterial pathogen that attacks many plant species. The symptoms of this disease generally appear on the lower part of the stem and in plants older than seven months; they are characterized by galls on the stem nodes. These galls grow considerably and show proliferation of buds on their epidermis. Affected plants may be stunted, and when the attack occurs in an early stage, it may cause dieback up to one of the main galls. The same plant may have several galls along the stem and even on the lower branches, but the disease is usually initiated through wounds leaf after old leaves fall, that become infected by infested soil splashed by the rain.

It is controlled by rotating cassava when more than 3% of the plantation is affected; desinfesting machestes (5% commercial formaldehyde); using always planting material taken from healthy plants; and burning all diseased material within the plantation.

# BACTERIAL ROOT ROT OF CASSAVA

*Pseudomonas solanacearum* has been reported as a pathogen of cassava in Brazil inducing wilt in young plants but not leaf spotting or gum exudation. However, strains of this pathogen have not been isolated affecting cassava since the report was published. In Malaysia, a recent report of this bacterial species describes plant wilting and heavy root rots, which indicates that perhaps some strains of the pathogen can also affect cassava. Considering the wide distribution of this pathogen around the world affecting many plant species, it appears that the biotype that affects cassava in Malaysia is pathologically different from known races and biotypes of this bacterial species. Consequently, caregul quarantinery precautions should be taken.

# MYCOPLASMAL DISEASES OF CASSAVA

## The Witches Broom Disease

This disease has been reported in Brazil, Venezuela, Mexico and observed in the Amazonas region of Peru. Reduction in yield can be relatively high, sometimes in excess of 80%. There are several types symptoms, probably due to different races or biotypesof the causal agent. Among them, the most important are:

1. Plants that show stunting and excessive proliferation of branches; shoots have small leaves and shortened internodes, without showing distortion or chlorosis.

2. Proliferation of shoots from cuttings; these are generally weak but grow without showing any other visible symptom of being affected.

3. Only a few weak and stunted shoots germinate from the cutting; they never reach normal size.

As the disease is transmitted mechanically and through the use of cuttings taken from diseased plants, their elimination and the desinfestation of machetes (by heating or washing them with 5% formaldehyde) are indispensable for its control. Always it should be used disease-free material for planting.

ANTHOLYSIS IN CASSAVA (*MANIHOT ESCULENTA* CRANTZ) POSSIBLY CAUS-
ED BY MYCOPLASMA-LIKE ORGANISMS

Phyllody on cassava plants was frequently observed during
recent disease surveys in the Cauca Valley, Colombia. This
symptom has also been observed under experimental conditions
on some cassava clones rendered unsuitable for hybridization.
An investigation was undertaken to determine the cause of this
malformation in cassava.

MATERIALS AND METHODS

Disease Symptoms

Symptoms described are based both on greenhouse and field
observations. Glasshouse experiments were conducted at 24-26°C
and 80% RH under 8 h photoperiod of 20,000 lux.

Production of Experimental Plants

Healthy cassava material (clones "Secundina" and "Brazil
15") was originally obtained by meristem culture techniques
(Roca, 1980). Cuttings (20 cm), with and without flower malfor-
mation symptoms, were planted in 8 cm plastic pots containing
sterilized soil, in the glasshouse. Planted cuttings were fer-
tilized with NPK/granular fertilizer (10-20-10) (3 g/l) 25 days
after planting and subsequently every 15 days.

Microscopy

Fresh hand-cut sections of petioles, peduncles and young
stems of diseased and healty plants were stained for light mi-
croscopy according to Deeley *et al* (1979), using Dienes' stain
for mycoplasma-like organisms (MLO). For electron microscopy,
tissue samples of infected and healthy cassava plants were ac-
cording to the method of Jayasinghe and Dijkstra (1979), modi-
fied by increasing the fixing time to 24 h. The fixed tissues
were  then dehydrated in a graded series of acetonem infiltrat-
ed and embedded with epoxy resin (Spurr, 1969). Ultrathin sec-
tions were cut in a Sorvall Porter Blum microtome using a dia-
mond knife. The sections were first stained with 2% uranyl
acetate and then with lead citrate in 0.01 M sodium hydroxide
(Reynolds, 1963) for 30 min prior to observation with a Jeol
electron microscope.

RESULTS AND DISCUSSION

Disease symptoms are first observed as virescence of the
normally pinkishcream tepal, followed by hypertrophy and phyl-
lody (Fig.1A) to produce a syndrome known as antholysis (Bos,
1978). Apostasis is common in those flowers, with considerable
protuberance of the gynophore from which central proliferation
occurs (Fig.1B); such deformed flowers are sterile and abort
prematurely. In certain cases, the malformed flowers become
necrotic and remain attached to the plant for prolonged periods
of time. A similar situation occurs in male flowers. affected
plants never produce normal flowers.

Except for the presence of malformed flowers, affected
plants are not differentiated from healthy ones, since neither
loss in vigour nor witches' broom-type symptoms are observed
in diseased plants. Similarly, no diferences in germination
and rotting of affected cuttings were found in relation to con-
trols.

Cuttings obtained from affected plants reproduced antholy-
sis symptoms one month after planting. During this period, how-
ever, no flowers were visible in the healthy control plants
since, depending on the genotype, healthy cuttings normally pro-
duce flowers five months after planting.

Hand-cut sections of fresh petioles, penduncles or twigs
of diseased plants stained with Dienes' stain, showed darkly-
stained granular materials only in the phloem cells of diseased
plants (Figs. 2A and B).

Transverse ultrathin sections of tissues from twigs, petio-
les and the peduncle of six infected plants revealed the pre-
sence of MLO's in mature sieve tubes (Fig.3). they were always
confined to mature sieve elements and were not found in paren-
chymatous tissue. the MLO structures were pleomorphic mostly
oval to spherical in shape (Fig.3) and were bounded by a typi-
cal triple-layered membrane. The internal structure of the MLO
closely resembled those described by Plavsic-Banjal *et al* (1972)
and Beakbane *et al* (1972) for the MLO associated with lethal
yellowing of coconut. Several small spherical bodies were also
observed along with MLO (Fig.3).

Treatments with penicillin at 500 and 1000 ppm (a.i.) did
not control the disease. More than 90% of the treated plants
developed symptoms similar to those of the untreated diseased
controls. On the other hand only 10 and 30% of the total plants
treated with tetracycline or streptomycin respectively, at 1000
ppm, showed antholysis and even four months after the last anti-
biotic application symtom remission had not occurred on these
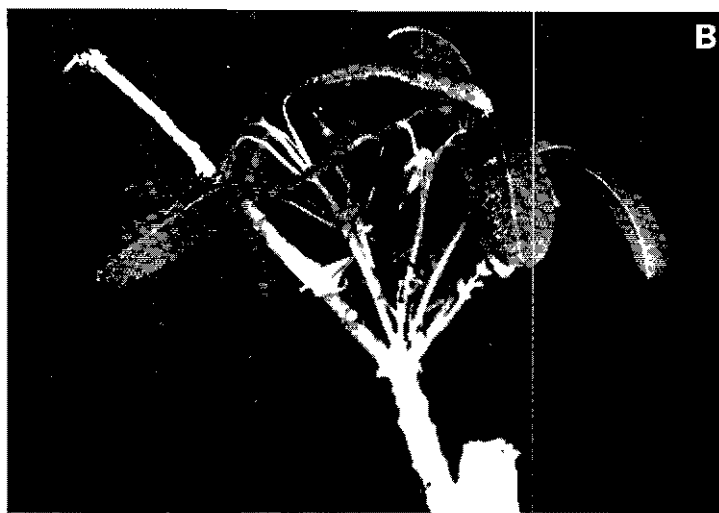
FIGURE 1.    CASSAVA 'SECUNDINA' CLONE SHOWING SYMPTOMS
OF ANTHOLYSIS.  A) HYPERTROPHY AND PHYLLODY
OF FLORAL PARTS (ARROWS INDICATE NORMAL
LEAVES).  INSERT: HEALTHY FLOWERS OF CASSAVA.
B) APOSTASIS (ARROW).
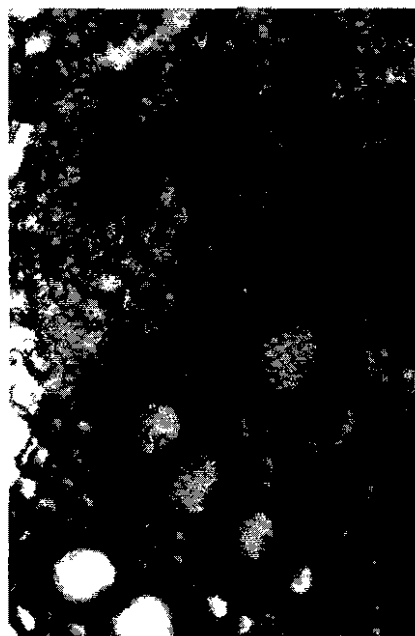
FIGURE 2. A) SECTION OF A PEDUNCLE OF A MODIFIED
FLOWER AFFECTED BY ANTHOLYSIS SHOWING DARK
GRANULAR MATERIAL (ARROWS) IN THE PHLOEM (P)
FOLLOWING TREATMENT WITH DIENES' STAIN. XY-
LEM VESSELS (Xy). B) HEALTHY CONTROLS (BAR
REPRESENTS 60 μm).

FIGURE 3.    PHLOEM CELLS OF A PETIOLE OF A CASSAVA PLANT
            EXHIBITING ANTHOLYSIS, SHOWING MYCOPLASMA-
            LIKE ORGANISMS (M) IN THE SIEVE TUBE.   DENSE
            SPHERICAL BODIES (ARROWS); CELL WALL (CW)
            NUCLEUS (N) CHLOROPLASTS (CH).

plants. The symptoms, however, were much less severe than on the untreated plants. Because penicillin acts on the cell wall Mahler and Cordes, 1969) which is lacking in MLO, the sensitivity of the causal agent to tetracycline, but not to penicillin suggests the association of MLO with the disease (Maramorosch *et al*, 1970, Ploaje, 1981). Streptomycin and tetracycline act on the ribosomes and RNA replication, respectively (Mahler and Cordes, 1969). The active concentration of both tetracycline and streptomycin (1000 ppm a.i.) needed to control the disease is similar to that reported for certain other MLO-associate plant diseases (La Yong-Joon, 1978; Quebral, 1978; Chill *et al*, 1978).

Results from chemotherapy and cytological observations suggest that antholysis in cassava may be caused by a MLO. This agrees with reports of phyllody in other crops which are also thought to be caused by MLO's (Ploaie and Maramorosch, 1969; Sutabutra, 1978; Ploaie, 1981; Hearon *et al*, 1976). Further studies to elucidate transmission, yield loss and control of the disease are in progress.


CASSAVA VIROLOGY


Viral Diseases

To date there have been 4 viruses, several virus strains and numerous virus-like agents reported infecting cassava worldwide.

The list of known viruses will increase as more of the virus-like agents are characterized and classified. Both African cassava mosaic virus (ACMV) and cassava common mosaic virus (CCMV) occur as different biological and serological strains.

Sufficient information is available to indicate that viruses are a major constraint to production and cassava improvement. The possible introduction of viruses into areas where they have not yet been reported must be miniminizal. Though the exchange of only virus indexed or "clean" cassava propagation materials. The probability that seeds or vegetative materials are "clean" is dependent on: (1) the method or combination of methods used for virus eradication; and (2) on the sensitivity of the detection method used to certify the material as virus-free. The combination of thermotherapy and meristem-tip culture with sensitive virus detection techniques such as the linked immunosorbent assay (ELISA) reduces the threat of inadvertent virus dissemination.

AFRICAN CASSAVA MOSAI DISEASE


This disease was first reported by Walburg in 1984. It occurs in all parts of east, west, and central Africa and adjacent islands (Storey, 1936; Storey and Nichols, 1938; Chant, 1959; Jennings, 1960a, 1970) and reported losses in yield from this disease range from 20 to 90% (Lefevre, 1935; Chant, 1959; Jennings, 1960a; Doku, 1965, Beck, 1971). This disease also appears in India but is noticeably absent from the Americas the recognised source of origin of the crop. It is probably a new or introduced disease to the crop in Africa.

African cassava mosaic disease caused by ACMV is the most serious cassava disease on the African continent in terms of geographic distribution and economic losses. ACMV is a geminivirus composed of paired virus particles, 20 x 30 nm in size, containing a circular single-stranded DNA (ssDNA) genome. The virus is transmitted by the whitefly, *Bemisia tabaci* with the rate of dissemination rapid in some regions.

For whiteflies to become virusliferous, it is necessary for them to feed for at least four hours on young diseased leaves followed by a further four-hour incubation period (Storey and Nichols, 1938; Chant, 1958; Jennings, 1960a). ACMV can be purified from the experimental host *Nicotiana benthamiana*. An antiserum has been produced that is suitable for use in the enzyme-linked ammunsorbent assay (ELISA). Recently the ACMV genome has been completely sequenced and found to consist of two circular ssDNA molecules, which are both required for infectivity.

The symptoms in cassava are characteristic of a mosaic disease. Early in the development of the leaf, chlorotic areas can be observed and leaflets are frequently distorted (Fig.1)


The development of resistant varieties has been possible through the use of inter-specific hybrids between *M. esculenta* and *M. glaziovii* (Storey, 1936; Jennings, 1960; Hahn and Leuchner, 1980). The planting of clean planting material is an effective control measure in areas where the reinfection rate is slow (Bock, 1984).


CASSAVA BROWN STREAK DISEASE


Brown streak disease was first recorded and described in 1936 (Nichols, 1950), and is reported only to occur along the coast of Africa and at altitudes below 3500 ft (Nichols, 1950;

FIGURE 1. CASSAVA MOSAIC DISEASE (AFRICAN MOSAIC). LEAF
SHOWING TYPICAL CHLOROSIS AND DEFORMATION

Jennings, 1960b). Because diseased roots are unfit for human
consumption losses van be considerable (Jennings, 1972; Lozano,
1972b), although the incidence and economic importance of CBSV
is low in comparison to ACMV. The elongated rod-shaped parti-
cles associated with the cassava brown streak disease have an
average length of 650 nm and are similar to viruses in the car-
lavirus group; however, their role in the etiology of the dis-
ease is still not clear.

A rod-shaped virus can be mechanically-transmitted from
infected cassava plants to *Nicotiana debneyi* (Bock, 1984) and
*Petunia hybrida* (Lister, 1959). The virus can also be readily
graft-transmitted (Storey, 1936; Nichols, 1950). Insect trans-
mission has not been demonstrated (Lister, 1959); although re-
cent circumstantial evidences has implicated the whitefly *Bemi-
sia hancocki* (Bock, 1984). Infected plants show chlorosis of
the leaves, necrosis of the root storage tissues and leaf scars
remain longer than expected after normal leaf drop. Brown le-

519

sions sometimes occur on the young green stems (Nichols, 1950; Jennings, 1960b).

Effective control has been obtained by using disease-free planting material. Resistant varieties have been reported (Jennings, 1960b; Nichols, 1950; Storey, 1936).


CASSAVA COMMON MOSAIC DISEASE


Cassava common mosaic disease, caused by the cassava common mosaic virus (CCMV) was just reported from Brazil and later from Peru and Colombia, and is probably present in all cassava-growing regions of Latin America. Although the incidence of CCMV-infected plants is low, yield losses per plant can be as high as 60%. As there are no known vectors reported, the main means of dissemination is via infected planting material. CCMV is a member of the potexvirus group with elongated rod-shaped particles 15 nm wide by 495 nm long          . The virus produces a diagnostic reaction on the indicator plants, *Chenopodium quinoa* and *Nicotiana benthamiana*, reaching high concentrations in the hosts; CCMV can be readily purified for antiserum production. CCMV produces a chlorotic mosaic on cassava; mosaic is mild and not associated with leaf distortion on most clones          while on some clones the mosaic can be very apparent. Effective control measures include the use of virus-free planting material, clean propagating tools, and roguing of infected plants.


CASSAVA VEINAL MOSAIC DISEASES


Cassava veinal mosaic disease caused by cassava veinal mosaic virus (CCMV) was first reported in Brazil in 1940. The disease has not been found in any country and within Brazil the incidence of this disease is very low. The spherical virus particles, 40 to 50 nm in diameter, associated wit CVMV-infected plants have been purified and an antiserum produced. Virus particles contain a double-stranded DNA genome, making CVMV a tentative member of the caulimovirus group. There are no known vectors of CVMV, and the main source of dissemination is via infected planting material.

The virus can be readily graft-transmitted but the mechanical transmission rate to *Datura stramonium* is low. Symptoms of the disease on cassava are characterized by vein-clearing and slight leaf curling (Fig.    ). As the incidence of this disease is very low and field spread in negligible, roguing infected plants is the recommended control practice.

## LATENT VIRUS

A rhabdovirus, with a particle size of 50-70 nm x 200-250 nm, was observed in thin sections of cassava leaves with the aid of electron microscopy (Costa *et al*, 1970; Kitajima & Costa, 1979). The virus was first described from Brazil in 1970. There are no known vectors and the virus is not mechanically transmissible. The virus produces no visible symptoms and is not considered economically.

## FROG SKIN DISEASE

Frog skin disease (FSD) was first reported from southern Colombia in 1971. Roots from infected plants are reduced in size and are usually not marketable because of the presence of deep cortical cracks or scalelike formations on the epidermis (Fig. ). There are no distinctive symptoms on the aboveground parts of infected plants. The etiology of FSD is unknown the disease is associated with elongated, rod-shaped and spherical viruslike particles. The causal agent has not been mechanically transmitted; but it is graft transmissible and can be disseminated via infected planting material. There is inconclusive evidence that whiteflies may be involved in the field transmission of at least one of the associated viruslike agents.

Effective control measures implemented in Colombia, include the introduction of virus-free planting material, the use of clean propagation tools, and the selection of stakes from plants without visible FSD root symptoms.

## CARIBBEAN MOSAIC DISEASE

A severe mosaic disease (CMD) of cassava grown in the Caribbean coast region of Colombia was described in 1981. A similar disease has also been reported from Cuba and Panama. Susceptible plants are stunted with deformed curled leaves, which exhibits brilliant yellow mosaic (Fig. ). Thus far a potexvirus, related to CCMV, has been isolated from CMD-infected plants, but reinoculation of cassava does not produce typical CMD symptoms. The etiological agent is readily graft transmissible and is disseminated via infected planting material. Field transmission into plots of healthy plants is rapid, suggesting the existence of a biological vector. The use of resistant varieties is the only control practice available at this time.

## SYMPTOMLESS VIRUSLIKE DISEASE

In 1982 a mosaic-producing agent was detected in several apparently symptomless cassava clones by grafting to scions of a susceptible indicator clone (Fig.   ). An elongated rod-shaped virus can be mechanically transmitted from symtomless plants to the local lesion host *Chenopodium quinoa*. The role the viruslike particle has in the etiology is under investigation.

## VIRUS DETECTION METHODS AVAILABLE FOR INDEXING CASSAVA

Various virus detection techniques are currently available for indexing cassava for the presence of viruses and viruslike agents. These techniques differ considerably with respect to sensitivity, ease of manipulation, cost and labor inputs. The choice of a particular technique or combination of techniques depends on the facilities and personnel available and the level of confidence required for certifying a plant virus free. An institute involved in the shipment of cassava germplasm between continents or between countries would be expected to make the greatest effort to increase the probability of ensuring freedom from all known viruses.

Cassava virus detection methods can be based on the observation of symptoms or on the detection of virus particles and viral products. Detection based on symptonatology includes the observation of characteristic symptoms on cassava, on inoculated indicator plants, or on grafted susceptible scions. Cassava virus particles or viral products can be detected using virus-specific antiserum in the ELISA or immunosorbent electron microscopy (ISEM) tests. The isolation of double-stranded RNA (ssRNA) and nucleic acid hybridization tests permits the detection of cassava viruses without the use of virus-specific antiserum.

The reliability of detection methods based on the observation of symptoms can be increased by observing plants maintained under optimal conditions for symptom expression. For example, the symptoms of CMD are not expressed at temperatures above 28 °C. In this case plants are grown in a controlled environment for symptom development. Howeverm in the case of FSD, root symptoms are readily apparent under field conditions. At the Centro Internacional de Agricultura Tropical, for example, the roots of plants selected for virus indexing are routinely checked for symptoms of FSD in the field; and cuttings taken from these plants are sprouted at 25 to 30°C in the glasshouse to enhance the symptom expression of other viruses. It is also possible to select apparently ACMV-free clones in Kenya based on the absence of visible mosaic symptoms.

The bioassay of machanically transmissible cassava viruses to indicator hosts is a sensitive indexing method if a very susceptible bioassay host is available, virus concentration in the test plant is high, and environmental conditions are optimal for symptom expression. The Nigerian isolate of ACMV produces a severe, systemic infection in inoculated *Nicotiana benthamiana* plants. The Kenyan isolate of CBSV can be bioassayed on *N. debneyi*. Graft indexing is a very sensitive method if a highly susceptible indicator clone is used in the graft. the native Colombian clone Secundina has been selected at CIAT for its high susceptibility to the frog skin, Caribbean mosaic and latent diseases in Latin America. When a Secundina scion is grafted onto an infected rootstock, a moderate severe mosaic symptom is expressed by Secundina. Grafting provides a method for indexing viruses and viruslike agents that are not mechanically transmissible; e.g., CMD. Although a graft-indexing program requires minimal facilities and training, the procedure is labor intensive and indexing results are not available for several weeks. Another major constraints is the difficulty in maintainin virus-free stocks of the indicator clone.

Sensitive serological tests are available for indexing cassava for viruses that have been isolated, purified and an antiserum produced. ELISA is a highly sensitive, efficient and rapid method for detecting ACMV and CCMV in cassava. The immunosorbent electron microscopy (ISEM) test can also be used for detecting ACMV and CCMV. ELISA is suited to a large-scale virus-indexing program so hundreds of plants can be tested in a day with results available within 36 hours. ISEM can only be used by personnel with access to an electron microscope facility. The preparation of test material and examination of grids is simple and rapid, but the use of the electron microscope is expensive to it can only be used for a limited number of samples. Although ISEM is not as sensitive as ELISA, it has the advantage of providing a virus identification within several hours.

Nucleic acid or spot hybridization and isolation of viral-specific dsRNAs have recently been applied for detecting cassava viruses. Neither test is based on the use of virus-specific antiserum. Spot hybridization has been adapted for detecting ACMV in cassava. The procedure is based on the use of a radio-actively labeled DNA molecule that is complementary to the viral genome, to "probe" spots of leaf sap for the presence of viruses. The test is highly sensitive and suited for processing large numbers of samples. Isolation of dsRNAs as a plant virus detection method is being tested for detecting cassava viral infections. Although dsRNA molecules are not normally a component of normal plant cells, they are readily produced during the replication of many plant viruses. Therefore, the detection of dsRNA in a plant can be used as a general indicator for viral infections. This technique is particularly suitable for detect-

ing uncharacterized viruses for which an artiserum or nucleic acid probe is not available. The extraction and analysis of dsRNA are somewhat laborius, amking the test more suited for indexing a limited number of mother plants than as a general screening method.

The general research objectives of cassava virology research at CIAT include the following:

A. Description.- Describe and photograph symptoms of virus diseases on cassava and other host species.

B. Mechanical Transmission.- The use of sap inoculation for the identification of local lesion and systemically-infected hosts will be attempted. Experimental local lesion hosts are useful for diagnosis, isolation of "pure" virus cultures and quantifying infectious virus titers. Systemic hosts, with high virus titer, are required as alternatives to cassava for virus purification. Several of the Latin American cassava viruses are difficult or as yet impossible to mechanically tranmit. Varying the pre-inoculation treatment of test plants, type of buffer, ionic strength, pH, and buffer additives can be useful in increasing transmission success.

C. Mode of Field Transmission.- The elucidation of the mode of field transmission is important both for virus identification and the development of control strategies. Isolation of vectors is a means of transmitting mechanically non-transmissible viruses and for isolating individual viruses from mixed infections. Knowledge of the virus-vector relationship is essential for understanding disease epidemiology and formulating disease management practices.

## Specific Objectives

1. Collection of potential vector insects from diseased fields.

2. Maintenance of non-viruliferous insect colonies for transmission studies.

3. Determine transmission characteristics

   - acquisition feeding period
   - latent period
   - inoculation feeding period
   - retention period

D. Electron Microscopic Properties.- The examination of negatively-stained particles in crude sap separations can provide a means of grouping unknown viruses by comparing the shape and size of the particle with similar described viruses. Immunosorbent electron microscopy (ISEM), combines serology with electron microscopy and offers a rapid means for virus diagnosis. ISEM enhances the sensitivity of the leaf dip technique by selectively absorbing serologically-related virus particles to the grid surface. The observation of characteristic viral inclusions in thin-sectioned plant tissue has been used for the identification of many viruses. Virus particles, inclusions produced by aggregates of viral particles and other ultrastructural changes are diagnostic of infections by particular viral groups.

Specific Objectives

1. Observe negatively-stained leaf dip preparations.

2. Adapt ISEM using available antisera to cassava viruses and serologically-related viruses.

3. Observe thin-sectioned plant material for characteristic viral inclusions.

E. Serology.- Serology is useful for the rapid identification and detection of plant viruses. The precipitin-based serological techniques (tube precipitin and agar double diffusion) lack the sensitivity required for virus detection but are useful for determining serological relationships. The enzyme-linked immunosorbent assay (ELISA) is one of the most sensitive viral detection methods currently available but is dependent on the availability of virus specific antisera. A long range objective is the preparation of an antiserum to each of the important Latin American viruses.

Specific Objectives

1. Determine if any of the Latin American cassava viruses are serologically related to other cassava viruses.

2. Production of high titered antiserum

3. Develop serological methods for the detection of cassava viruses.

F. Purification Methods.- The development of effective
but simple purification methods are essential for virus charac-
terization and the production of antisera. Cassava is not an
ideal plant for virus purification so the identification of al-
ternate virus propagation hosts is necessary. The choice of
organic solvents of detergents, buffers and additives, buffer
ionic strength and pH, polyethylene glycol precipitation and
sucrose or glycerol gradients are all important variables in
the development of a purification method.

## Specific Objectives

1. Atempt to identify local lesion and propagation hosts
for each Latin American cassava virus.

2. Develop purification methods that yield infectious vi-
rus preparations with minimal host contamination.

G. Physico-chemical Properties.- The identification of a
plant virus is not complete without an analysis of the physical
and chemical properties of the purified virions. Physical pro-
perties include the sedimentation coefficient in linearlog su-
crose gradients or in analytical ultracentrifugation and the
particle bouyant density is cesium chloride or sulphate gradients.
The determination of the type, strandedness and molecular weight
of the virion nucleic acid and capsid protein are essential.

H. Virus Detection Methods.- The sensitive and rapid anti-
serum-based ELISA technique is used for detecting viruses in
many crop species. This test is amenable to large-scale plant
health testing programs. CIAT is currently using ELISA for de-
tecting two isolates of CCMV. However antisera is nor available
for other viruses.

Methods based on detecting viral specific nucleic acids in
infected plants may be applicable to cassava and should be test-
ed. The presence of PSTV is routinely assayed in potato by po-
lyacrylamide gel electrophoresis (Page). The use of radioacti-
vely-labeled copy DNA probes has recently increased the sensiti-
vity of PSTV detection. The detection of dsRNA in plants indi-
cates a viral infection. The sensitivity of dsRNA detection
can be increased using hybridization techniques.

## Specific Objectives

1. Adapt the most sensitive methods available for the de-
tection of Latin American cassava viruses.

I. Epidemiology.- The incidence and rate of field spread of most cassava viruses in Latin America has not been determined. An understanding of the epidemiology of these diseases is necessary for designing control practices.

Specific Objectives

1. Survey and sample fields in major cassava growin regions in Latin America.

2. Approximate rate of field virus spread in small plots.

J. Disease Management.- Disease management strategies will be based on information from the above objectives.

FUNGAL DISEASES

Many fungal diseases of cassava, varying considerably in their distribution and importance, have been reported. Those diseases considered to be most widespread or important in particular cases are described here as leaf diseases, stem-rots and root-rots.

Leaf Diseases

1. The brown leaf spot.- Brown leaf-spot *Cercosporidium henningsii*) is probably the most important of all the cassava leaf diseases, This disease is widely distributed and can be found in Asia and North America in addition to Africa and Latin America. Attacking *Manihot glaziovii* (cera rubber), *M. piauhynsis*, and by artificial inoculation, *Ipomea batatas* (sweet potato), in addition to *M. esculenta* (Viegas, 1941; Golato, 1963; Ferdinando *et al*, 1968; Powell, 1968, 1972; Golato and Meossi, 1971).

*C. henningsii* grows in the intercellular spaces of the leaves and produces stromata from two to six vells in depth and from 20-45 µ in diameter. From these stromata conidiophores are produced in dense fascicles. The conidiophores are pale olivaceous brown (medium-dark in mass), uniform in colour and width, unbranched, 0-2 midly geniculate, rounded at the tip with a small to medium spore scarm straight or nearly so and measuring 3-5 x 10-50 µ, rarely as long as 100 µ with the longest ones sparingly septate. The amphigenour conidia, produced singly at the apex of each conidiophore, are cylindric, straight or slightly curved, with both ends bluntly rounded or with a short abconic

base, plainly 2-8 septate, pale olivaceous and measuring 4-6
(7) x 30-60 (85) µ (Chupp, 1953; Powell, 1968, 1972). Black
perithecia, 100 µ diam, ocassionally appear scattered in the
necrotic tissue of the foliar spots on the upper surface on the
leaf. this asci are elongate-clavate, eight-spored, sub-sessi-
le, 55-72 x 10-13 µ. The ascospores are ovoid, uniseptate,
constricted at the septum, 17-22 x 5.2-6.8 µ. The upper cell
of these spores is of greater diameter than the lower and is
drawn out as a cangle flame (Chupp, 1953; Powell, 1972).

The perfect state of *C. henningsii* was reported as *Mycos-
phaerella manihotis* Ghesquiere Henrard non Sydow (Ghesquiere
and Henrard, 1924; Ghesquiere, 1932) and later corroborated by
Chevaugeon (1956). However, the genetic relationship between
the stages has not bee proven. Powell (1972) suggested a new
nomination needs to be provided for the sexual state as the one
in use is a later homonym of the name given by Sydow (1901).

*C. cassavae* Ell. & Ev.; *C. manihotis* P. Henn., *C. cearae*
Petch, *C. manihoticola* Stev. Ined., *C. manihotis* P. Henn., *Hel-
minthosporuim manihotis* Rangel; *H. hispaniolae* Cif., and *Septo-
gloerum manihotis* Zinn, are all considered to be synonymous with
*C. henningsii* (Ciferri, 1933; Chupp, 1953; Powell, 1972).

Symptoms on cassava are characterised by leaf spots on both
sides of the leaves. On the upper surface the spots appear uni-
formly brown with a distinct darker border (Fig. 1). On the
lower surface the lesions have less distinct margins and in the
centre the brown spots assume a greyish cast because of the pre-
sence of conidiophores and conidia of the fungus. As these flat
circular lesions, 3-12 mm diam, grow they become somewhat irre-
gular and angular in shape as they are lim·ted by the leaf mar-
gin or major veins. Small veins within the lesions appear black.
Sometimes, depending on the susceptibility of the variety, an
indefinite halo or blighted area is present around the lesions.
As the disease progresses infected leaves turn yellow and dry,
and eventyally drop. Susceptible varieties can thus be severe-
ly defoliated during warm rainy seasons.

Primary infections are initiated in new plantings when wind
or rain carry conidia from lesions on old fallen infected tissues
to infection courts on leaf surfaces. If sufficient moisture
is present, the conidia germinate, producing branched germ tu-
bes which frequently anastomose. Penetration occurs through
stomatal cavities and invasion of the tissues through intercel-
lular spaces. In warm, humid conditions infection usually oc-
curs within twelve hours (Wallace, 1931; Ciferri, 1933; Viegas,
1941, 1943a, 1943b; Chevaugeon, 1956).

When these lesions mature, conidiophores are produced from
the stomata. Secondary disease cycles are repeated throughout
the rainy season whenever conidia are carried to new sites of

FIGURE 1.   BROWN LEAF-SPOT (*Cercosporidium henningsii*).
LARGE BROWN LESIONS WITH DISTINCT BORDERS.

of infection by wind or rain.  The fungus survives the dry sea-
son in old lesions, often on fallen leaves, and renews its ac-
tivity with the coming of the rainy season and the renewed
growth of the host.

Chevaugeon (1956) demonstrated that on a given plant the
older, lower leaves are more susceptible than the younger, up-
per leaves.  This is corroborated by other authors.  However,
it has been observed that some susceptible species (*M. cartha-
genensis*) and cultivars of *M. esculenta* may be severely and
evenly attacked.  Leaflets, young leaves, petioles, and even
fruits of *M. carthagenensis* have been observed with severe dis-

ease symptoms. It is reported that plants that have been "hard-
ened" by unfavorable growing conditions become more resistant
(Viennot-Bourgin and Grimaldi, 1950) but no differences in sus-
ceptibility between plants grown on rich or poor soil were found
(Chevaugeon, 1956).

Cultural practices, such as wider spacing, directed towards
reducing excess humidity in the crop stand are recommended to
reduce infection (Springensguth, 1940; Golato, 1963; Golato and
meossi, 1966). The use of copper oxides and copper oxychlorides
suspended in mineral oil applied at a rate of 12 1/ha have been
reported to give good control (Golato, 1963; Golato and Meossi,
1971). However, the best control of this disease is obtained
by planting resistant varieties. Significant differences in
varietal resistance have been reported in Africa (Chevaugeon,
1956; Umanah, 1970), Brazil (Viegas, 1941, 1943a, 1943b) and in
the extensive collection of cassava varieties at CIAT, Colombia
(CIAT, 1972).

The White Leaf-spot

White leaf-spot (*Phaeorannularia manihotis*) is commonly
found in the humid but cooler cassava-growing regions and has
been reported in certain areas of Asia, North America, tropical
Africa, and Latin America (Viegas, 1941; Viennot-Bourgin and
Grimaldi, 1950; Chevaugeon, 1956; Castaño, 1969; CIAT, 1972).
In these areas this pathogen may cause considerable defoliation
of susceptible varieties of *M. esculenta*, the only reported host
species (Viegas, 1941; Chevaugeon, 1956).

*P. manihotis* form slight stromata in infected leaves from
which conidiophores are produced in loose fascicles. The coni-
diophores which emerge through stomata are usually olivaceous
brown, uniform in colour and width; rarely branched, 1-15 geni-
culate, sub-truncate at the tip with a fairly large spore scar
and measure 3-5 x 50-200 . The hypophyllous conidia are hya-
line to subhyaline, obclavate-cylindric, with bluntly rounded
ends, 1-6 septate, straight or nearly so, and measure 4-8 x 20
-90 µ(Chupp, 1953; Powell 1968, 1972).

While the name *Cercospora caribaea* Chupp and Ciferri was
widely accepted for this fungus, Powell (1972) states that the
name is not at present valid and will only be validated by the
publication of a full latin description. This species can easi-
ly be distinguished from *Cercospora* spp. It has recently been
changed *M. esculenta* to *P. manihotis* by the leaf symptoms and
by the hyaline conidia produced (Chupp, 1953; Powell, 1968).

Lesions caused by *P. manihotis* are smaller and different
in colour to those induced by *C. henningsii*. They are circular
to angular, usually 1-7 mm diameter, and white, or rarely yellow-

530

ish brown (Fig.2). The lesions are sunken from both sides to
about one-half the thickness of the healthy.leaf blade. While



FIGURE 2. WHITE LEAF SPOT (*P. manihotis*). SMALL WHITE
LESIONS WITH DISTINCT VIOLET-BROWN BORDER AND
DIFFUSE YELLOW HALOS.

the white spots remain distinct, the lesions frequently have a
diffuse coloured border on the lower leaf surface. The border
sometimes appears as an irregular violet-brown line surrounded
by a yellow or brownish halo. The centre of the spots are given
a greyish velvety aspect during the fructification of the patho-
gen which occurs predominantly on the underside of the leaf.

Penetration occurs through stomatal cavities and invasion
of the tissues through intercellular spaces. When the leaf
spots thus produced reach about 5-7 mm a stroma is formed from
which the conidiophores are later produced. Secondary disease

cycles are repeated throughout the rainy season when the coni-
dia are dispersed by rain splash. The fungus survives the dry
season in old, infected tissues and renews its activity with
the coming of the rainy season and the renewed growth of the
host.

Recommended control measures for this disease are similar
to those for brown leaf spot. Specific resistant varieties
have not been reported, but field observations suggest such re-
sistance exists.

The development of the two diseases, brown and white leaf
spots, is similar but generally brown leaf spot is more common
in hot, dry regions and white leaf spot in humid, coller cassa-
va-growing areas. These distribution differences reported in
Africa (Chevaugeon, 1956) and Latin America (CIAT, 1972) are
probably the result of differences in temperature and moisture
responses of the two causal fungi. The optimum temperatures
for conidial germination of *C. henningsii* and *P. manihotis*
are 39 and 33°C, respectively, and the maximum temperatures to
allow germination are 43 and 33°C, respectively. Conidia of *C.
henningsii* will germinate at 50% R.H. with optimum germination
at 90% while conidia of *P. manihotis* need to be immersed in wa-
ter for normal germination. Nutritional studies have also re-
vealed differences between the two fungi; *C. henningsii* is able
to utilise acetate, citrate, and various amino acids but not
pentoses. *P.manihotis* however utilises pentoses as energy and
carbon source but does not generally utilise trioses (Chevaugeon
1956; Powell, 1968).


## The Blight Leaf-spot

*Cercospora viscosae* Muller and Chupp is the causal agent
of a diffuse leaf spot in the warm cassava-growing areas of Bra-
zil and Colombia (Viegas, 1941; CIAT, 1972). Leaf sports are
large and brown without definite borders. Each spot frequent-
ly covers one-fifth or more of the leaf lobe. The upper sur-
face of the spot is uniformly brown but on the under surface
the centres of the brown lesions assume a greyish cast because
of the presence of conidia and conidiophores of the fungus.
The general appearance of the lesions is similar to those in-
duced by *Phoma* sp. but can be distinguished form the latter
which usually have concentric rings around the lesions on the
upper leaf surface.

The fungus does not form a stromata but sporulates profu-
sely. The conidiophores produced in coremoid fascicles are
dark reddish-brown, measuring 4-6 x 50-150 µ. The conidia pro-
duced are cylindro-obclavate and 4-6 x 25-100 µ (Chupp, 1953).

*C. viscosae* has only been found infecting *Manihot* spp.

The disease occurs during the rainy season in warm cassava grow-ing areas where brown leaf-spot is also usually prevalent. The disease is not usually serious and is confined to the older lea-ves where some defoliation may occur.

*C. manihobae* Viegas has been reported to induce leaf spots on *M. esculenta* in Brazil (Viegas, 1941, 1943b, Chupp, 1953). Leaf spots are reported (Viegas, 1941, 1943b) to be characteris-tically show-white in appearance, but a full description of the disease is not available.

The fungus produces medium dark coloured conidiophores mea-suring 3-5 x 50-200 μ. The conidia are hyaline to subhyaline, obclavatecylindric, and 4-8 x 20-90 μ (Chupp, 1953).

## Phoma Leaf-spot

This disease is commonly found in the cooler cassava-grow-ing areas of Colombia (CIAT, 1972) and Brazil (Viegas, 1943a) and has also been reported in the Philippines (Sydow, 1913), Tropical Africa (Vincens, 1915), and India (Ferdinando *et al*, 1968). During rainy season and when the temperature is below 22°C, this disease may cause severe defoliation of susceptible varieties, finally resulting in die-back of the plants. The disease has also been reported to occur on *Manihot heptaphylla*, *M. dichotoma* (Reinking, 1919; Viegas, 1943a) and *M. aipi* (Spe-gazzini, 1913; Viegas, 1943a) in addition to *Manihot esculenta* (Viegas, 1943a).

The causal agent of this disease has not been clearly de-fined, and several *Phyllosticta* spp. have been reported (Sydow, 1913; Vincens, 1915; Reinking, 1919; Viegas, 1943a; CIAT, 1972) as inducing the same disease syndrom. Vincens (1915) first des-cribed the causal agent as *Haplographium manihoticola* Vincens, but the pathogenicity of this fungus was later questioned by Viegas (1943a). *Phyllosticta manihoticola* Sydow (Sydow, 1913), *P. manihot* Sacc. (Saccardo, 1931), and *P. manihobae* Viegas (Viegas, 1943a) have all since been reported as pathogenic on cassava. As the full definition and taxonomic validity of these species have not been fully determined, the possibility remains that they could be synonymous and that there is only a single cassava pathogenic species. Recent studies and observation in-dicate that this fungus should be classified as a *Phoma* sp. A full taxonomic study of a wide range of pathogenic isolates is urgently needed to clarify this point.

The causal fungus produces numerous epidermal pycnidia which are dark-brown, globose, and borne singly or in small clusters on infected leaves and stems. The pycnidia are 100-170 μ in diameter with walls formed of polyhydrical cells and have an ostiole measuring 15-20 μ. The conidiophores are short

and hyaline and produce small (15-20  ), onecelled, ovoid to
elongate conidia (Viegas, 1943a; Ferdinandc *et al*, 1968).   The
fungus isolated in Colombia forms profuse pycnidia in concen-
tric rings on lima bean agar.

The disease on cassava is characterised by the presence of
large brown leaf spots, usually with indefinite margins.  These
lesions are commonly found at the tips or edges of the leaf lo-
bes or along the midrib or main veins.  The upper surface of
the lesions initially consists of concentric rings formed by
brown pycnidia (Fig. 3).  These rings are frequently absent
from old lesions as mature pycnidia are washed off by rain drops.
In these cases the uniformly brown lesions may resemble those
caused by *C viscosae*.  On the lower surface few pycnidia are
produced so the lesions are uniformly brown.  Under conditions
of high relative humidity, the lesions may be covered with a
greyish-brown hyphal weft.  On the underside of the leaves the
veins and veinlets around the lesions become necrosed thus form-
ing black strings radiating out from the lesions.  These lesions
grow, causing a leaf blight, and finally the whole leaf and pe-
tiole become dark brown and are necrosed.  At this stage the
leaves wilt and then drop, in some cases causing extensive de-
foliation.  In severe infections the fungus also attacks the
young shoots causing a die-back (Fig.3 ).  Diseased stems turn
brown and are frequently covered with pycnidia.

Field observations suggest that the older lower leaves
may be more resistant then younger upper leaves.  However, young
leaves, fully expanded mature leaves, and green stem parts have
all been seen with severe disease symptoms.  It has also been
observed that disease occurrence is correlated with conditions
permiting spore germination.  Maximum spore germination has
been observed between 20 adn 25°C and artificial inoculations
succeeded only at temperatures below 25°C.  Similarly, under
field conditions the disease is always found at higher altitu-
des or in lowland areas during the rainy season.  Survival of
the fungus during dry periods or from one season to another is
not understood.  It is suggested (Viegas, 1943b) that the fun-
gus may produce a sexual stage in infected stem and leaf debris,
but this has not yet been confirmed.

No control measures have been reported for the disease,
which can cause serious losses in certain areas under specific
environmental conditions.  Although no reports of varietal re-
sistance are available, field resistant cultivars have been
observed in naturally infected plantations in Colombia.  Chemi-
cal treatment during rainy seasons could also be beneficial in
those areas where the disease is known to be endemic.

FIGURE 3.    PHYLLOSTICTA LEAF-SPOT (*Phoma* spp.).    LEAFLET
SHOWING LARGE BROWN-LESIONS WITH CONCENTRIC
RINGS.    YOUNG STEM SHOWING DIE-BACK AND PRE-
SENCE OF PYCNIDIA.

Cassava Ash Disease

The disease was first reported in Africa (Saccardo, 1913)
but has since been reported in Latin America (Viegas, 1943a;
CIAT, 1972) and Asia (Park, 1934) and observed in several other
countries.    The disease is known only to cause yellowish unde-
fined leaf spots on *M. esculenta*.    Although widely distribut-
ed and of common occurrence, this disease is considered to be
of relatively minor importance.

The causal agent has been named as *Oidium manihotis* P.
Henn. the sexual stage of which has been described as *Erysi-
phe manihotis* (Ferdinando *et al*, 1968).    The fungal mycelium
is white, producing numerous haystoria on the host epidermis.

535

Conidiophores are upright and simple with the upper portion
increasing in both length and width as conidia are formed.
The conidia are oval or cylindrical, one-celled, hyaline, mea-
suring 12-20 x 20-40  , and produced in basipetal chains (Sac-
cardo, 1913; Viegas, 1943b; Ferdinando *et al*, 1968).

The first symptom of the disease is the appearance of
white mycelium growing over the leaf surface.  the fungus pe-
netrates the cells by means of haustoria, infected cells be-
coming chlorotic and thus forming yellowish undefined lesions
(Fig. 4).  Within these yellowish areas pale-brown angular
water-soaked spots of different sizes frequently develop and
necrose.  In certain varieties, the disease never progresses
beyond the yellowish undefined lesion  stage.  These symptoms
are sometimes confused with those induced by insects and spi-
ders.

Mature, fully expanded leaves appear to be the most suscep-
tible, but young leaves of certain varieties are also frequent-
ly infected.  The disease is found commonly during dry seasons
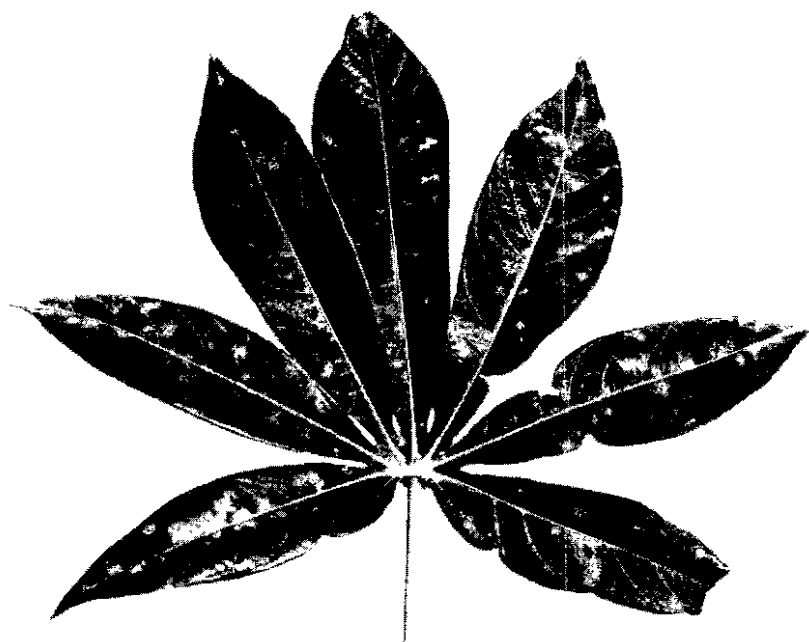in the warmer cassava-growing areas.



FIGURE 4.   CASSAVA ASH DISEASE (*Oidium manihotis*).   TYPI-
CAL UNDEFINED YELLOWISH LEAF LESIONS.

Although specific control measures against this disease are not generally considered necessary, resistant varieties have been observed (CIAT, 1972). It has also been suggested (Ferdinando *et al*, 1963) that spray applications of sulphur compounds control the disease.

## The Superelongation Disease (Summary)

Recent research on pathogen taxonomy, sexual reproduction, hosr range and physiology are summarized along with investigations into the nature of superelongation disease resistance. The previously unreported sexual stage of *Sphaceloma manihoticola*, causal agent of superelongation disease of cassava, is presented as an *Elsinoë* species (Loculoascomycetes, Myriangiales). Cross-inoculation studies, symptomatology, colony, characteristics, and morphological comparisons among isolates type specimens, and published descriptions support proposed synonymy of the *Elsinoë* from cassava with *E. jatrophae* and *E. brasiliensis* under the same *Elsinoë brasiliensis*. *Sphaceloma manihoticola* is retained, and *S. krugii* is combined with *S. poinsettiae* under the latter name. *In vitro* production of gibberellin A$_4$ by the pathogen was demonstrated through combined gas chromatography-mass spectrometry of purified culture extracts. Field resistant and field susceptible cultivars were treated with different concentrations of gibberellin A$_4$ and inoculated with the pathogen. No difference in response to the hormone was detected between resistant and susceptible cultivars when evaluated for change in length and susceptibility. All cultivars showed an increase in internode length at $10^3$ µg/µl hormone concentration, and all showed increased level of disease over control when inoculation followed hormone application. Regardless of field susceptibility, stem tissue of all cultivars tested develop resistance to the pathogen after about 8 days. Hormone production appears to confer an advantage to the pathogen by inducing growth and increasing the amount of susceptible juvenile tissue. Disruption of stem cuticle significantly increases level of disease as measured by number of lesions, percent of susceptible tissue diseased, and number of diseased internodes. Inoculations of selected cultivars of diverse origins and morphology with isolates of diverse origins in all combinations yielded variable, but significant cultivar x isolate interactions suggestive of pathogenic specialization. It is hypothesized that specific host-isolate incompatibility is only part of a complex of resistance mechanisms in field resistant cultivar.

The superelongation disease of cassava, firs reported in the Tolima Valley of Colombia in 1972, has since been reported throughout wide areas of South and Central America and the Caribbean. The CIAT cassava pathology section has conducted re-

search on disease etiology, physiology, and epidemiology, and
pathogen taxonomy and physiology, much of it in cooperation
with Cornell University. This paper summarizes most important
results of these studies. Detailed data supporting the find-
ings here have or will be published elsewhere.


I. Pathogen Taxonomy and Sexual Reproduction

The genus *Sphaceloma* de Bary (Melanconiales) currently
composes more than 50 species, the majority in tropical and
subtropical regions. The pathogen attacks flowers, fruits,
leaves, and stems, causing characteristic scab lesions as well
as necrotic leaf spots. Conidia are small, unicellular and hy-
aline, formed in a more or less acervulus-like structure or,
more commonly on continuous fertile layers of densely packed
phialidic conidiophores. Under certain conditions, some spe-
cies may form a larger, 0-2 septate, pigmented, thick-walled,
spindle-shaped spore. This form, originally described from
*Sphaceloma fawcetti* Jenking has been referred to as the "faw-
cetti" conidium and has been implicated in long distance wind
dissemination of the pathogen.

the genus *Elsinoë* Racib (Loculoascomycetes, Myriangiales)
contains over 40 species and has been shown to be the perfect
state of all but one species of *Sphaceloma* for which the sexual
stage is known. Host symptoms are identical to those caused
by *Sphaceloma* spp. Bitunicate asci, found solitary in locuses,
usually contain eight hyaline or slightly pigmented ascospores
which are commonly 3-septate, often with a longitudinal septum
in one or more internal cells.

In 1950 Bitancourt and Jenkins described a species of *Spha-
celoma, S. manihoticola* on cassava (*Manihot esculenta* Crantz,
Euphorbiaceae). Their description and decision to consider it
a new species was based entirely on symptomatology and host po-
sition within the Euphorbiaceae, since no spores or other fun-
gal reproductive structures were visible in their specimens.
They also observed symptoms which they attributed to the same
pathogen on *M. glaziovii* Muell. Arg., but made no mention of
internode elongation in their description of symptoms. Bitan-
court and Jenkins stated clearly that they considered the new
species as provisional, pending later opportunity to examine
fresh specimens containing reproductive structures.

Symptoms of superelongation disease include necrotic leaf
spots, hypertrophic leaf-vein, petiole and stem cankers, cha-
racteristic of scab disease caused by *Sphaceloma*. In addition,
severly affected plants show marked elongation of the interno-
des, from which the disease name is derived. The causal agent
was identified as a species of *Sphaceloma* by Krausz who decid-
ed that it should be considered *S manihoticola*, even though it

538

was impossible to determine if it was the same species described by Bitancourt and Jenkins. Prior to this study, no *Elsinoë* had been reported from *Manihot* spp.

Since 1942 several species of *Sphaceloma* *Elsinoë* have been described as pathogens on weedy and ornamental plants related to cassava in Central and South America. *Euphorbia brasiliensis*, *Eu. heterophylla* L, *Eu. hyperricifolia* L. and *Eu. prunifolia* L. are all weeds susceptible to *Sphaceloma-Elsinoë* spp. and common in cassava growing areas. Scab-susceptible *Eu. pulcherrima* Willd. (the "poinsettia") is a common ornamental shrub. *Jatropha curcas* L. as well as *J. aconitifolia* Muell. var *papaya* Arbelaez are trees often found in hedgerows between fields or as ornamentals in cassava growing areas.

Experimental

Isolates of *Sphaceloma* spp. were obtained from various Euphorbiaceous hosts in Latin America. These were cultured as described elsewhere and comparisons made of colony, conidiophore, and conidial morphology. Cross inoculations with all the *Sphaceloma-Elsinoë* species and hosts under consideration were conducted and conidial dimensions from each host compared. The morphology of an *Elsinoë* spp found on lesions of SED-affected cassava was studied, and the pathogenicity of single-ascospore isolates on cassava and other Euphorbiaceous hosts tested.

Findings

Colomny morphology of the different species of *Sphaceloma* was so variable as to be of limited usefulness as a criterion for distinguishing species. Conidial dimensions of isolates from several hosts considered to be hosts of distinct *Sphaceloma-Elsinoë* species were not found to differ significantly. No other reliable means of separating these species could be found. Conidial dimensions of isolates from cassava *Jatropha* spp. *Euphorbia brasiliensis* and *Manihot carthaginensis* were all found not to differ. Isolates from poinsettia (*E. pulcherrima*), *E. heterophylla*, and *E. prunifolia*, though significantly larger than the former group, did not differ significantly among themselves. The latter group also were found to produce fawcetti conidia, absent in the former group. Cross-inoculations with all possible host-pathogen combinations followed the same pattern as conidial dimensions.

Ascoma were observed on hypertrophic tissue of cassava leaves, petioles, and stems of plants collected during the rainy season when rains were regular. These structures were present on material from Mexico (Tabasco), Costa Rica, the Dominican Republic and Colombia (Departments of Casanare, Cauca, Magdale-

na, Meta, and Vichada). Extensive examination of material
from the other host species showing scab symptoms yielded no
sexual structures.

Ascoma on cassava are pulvinate (occasionally applanate)
and convoluted to smooth, solitary or coalescing. 20-130 μm
in diameter. They originate subepidermally and are composed
of a hyaline pseudoparenchyma with a distingly pigmented epi-
thelium, giving the structure a dark appearance when viewed
from above. Asci (usually with eight ascopores) are bitunica-
te and globose (13-22 μm in diameter) and occur singly in lo-
cules with poorly developed walls. Mature ascospores (11-14
x 3-7 μm) are hyaline, have transverse septa at which they
show slight constriction, and commonly have a longitudinal
septum in one or more of the internal cells. One end of the
spore is typically somewhat broader than the other. Germina-
tion is by production of conidia or direct, with one or more
germ tubes produced from each cell, near the septa. Fragmen-
tation of ascospores was occasionally observed, particularly
with dried specimens.

Based on comparisons of published descriptions and exten-
sive examination of herbarium type specimens, and the results
of the morphology and croos-inoculation studies, *Elsinoë anti-
desmae*, *E. heveae*, and *E. venezuelensis* are considered to be
distinct species and should be retained. However, the differ-
ences among *E. brasiliensis*, *E. jatrophae*, and the *Elsinoë*
from cassava are not considered sufficiently great to warrant
their continued treatment as separate species, and should all
be considered to be *E. brasiliensis*. *Sphaceloma manihoticola*
is, therefore, the correct name for the imperfect state of *E.
brasiliensis* as well as the causal agent of superelongation
disease. Similarly, *S. krugii* does not differ sufficiently
from *S. ponsettiae* to be considered distinct, and is combined
with the latter under the name *S. poinsettiae*.

The host range of *E. brasiliensis* is considerably expand-
ed and includes *Manihot* spp, *Euphorbia brasiliensis* (a cosmopo-
litan weed), *Jatropha curcas* and *J. aconitifolia* var. *papaya*
(ornamental trees). This has important implications for cassa-
va in other parts of the world. It is likely that should *S.
manihoticola* be introduced into Asia or Africa, weedy Euphor-
biaceous hosts will prevent its eradication. Similarly, as
has been the case with the CIAT station, complete eradication
of the pathogen appears impossible. Quarantine programs in
areas free of SED should be aware that other Euphorbiaceous
hosts notably the attractive ornamental *Jatropha* spp. may carry
cassava pathogens. Finallu, considering that there is a common
sexual stage, in addition to the wide host range, it is likely
that a high degree of pathogenic variability is present in most
populations of *S. manihoticola*.

## II. Pathogen Production of Gibberellin $A_4$

Krausz in early work on the disease unsuccessfully attempted to isolate a fungus-produced plant growth regulator responsible for the internode elongation. Plant hormones are known to be involved in many plant diseases. The classic case is that of *bakanae* disease of rice caused by *Gibberella fujikuroi* (Saw.) Wr. from which the plant hormone gibberellin (GA) was first isolated. The most obvious symptom of this disease is internode elongation of juvenile rice plants not unlike that observed in superelongation disease. Given this similarity in symptoms, we felt that a GA-like compound produced by the fungus may be responsible for the hypertrophic symptoms. This portion of the study was undertaken to determine if the pathogen is capable of producing a GA in vitro that reproduces secondary symptoms in the absence of the pathogen. Finding that the case, subsequent studies were conducted to determine if field resistance or susceptibility of cultivars were correlated to sensitivity to the hormone.

### Experimental

Isolates of *S. manihoticola* were grown in liquid medium for 2-3 weeks. Culture filtrate was purified by acid-base partitioning followed by silica gel column chromatography. Fractions from the chromatography were passed through combined gas chromatography-mass spectrometry and compounds identified based on the resulting mass spectra. Biological activity was determined using lettuce seedling hypocotyl bioassay and treatments of young cassava plants with purified hormone.

Young plants of cassava cultivars known to differ in their levels of field susceptiblity to SED were treated with increasing concentrations of gibberellin $A_4$. After 7-10 days, depending on experimental particulars, lengths of newly emerged internodes of treated and control plants were measured and plants then inoculated with conidial suspensios of the pathogen. After incubation, plants were evaluated for percentage of stem area diseased and length of diseased area. Data were analyzed using analyses of variance and covariance.

### Findings

Results of purification and analyses of fungal extracts demonstrated unequivocally that *S. manihoticola* produces gibberellin $A_4$ in vitro. Application of the purified hormone to cassava plants reproduced the stem elongation and less deformation symptoms. The only other fungus known to produce gibberellin A4, *Gibberella fujikuroi*, an unrelated pathogen of rice. All nine cultivars tested responded to applications of

$GA_4$ by increased internode length. Significant increases over control were detectable at concentrations of $1 \times 10^3$ µg/µl test solution. At each concentration and over all concentrations the amount and percet susceptible are diseased on field susceptible (FS) cultivars and field resistant (FR) cultivars differed significantly. No relation between minimum $[GA_4]$ required to elicit significant elongation response and varietal susceptibility was detected. While the rates of elongation as functions of increasing $[GA_4]$ differed significantly among cultivars there was no difference between FS and FR cultivars when the data were analyzed using analysis of covariance with $[GA_4]$ as the covariate and field susceptibility as a class variable.

All cultivars showed increasing amounts of disease with increasing hormone concentration. This suggests that GA4 production may confer an advatange to the pathogen by increasing the amount of susceptible juvenile tissue. As in the case of internode length, rate of change of the amount of diseased area did not vary with cultivar field susceptibility. In some cultivars, high $[GA_4]$ not only increased the total amount of disease on a plant, but also increased the percent of susceptible tissue involved in lesions, or tissue susceptibility, with important implications for secondary cycles and epidemic development in the field.


III. Some Characteristics of Resistance

In almost all national and international programs a key approach to improving cassava yields is breeding improved varieties. Because cassava is vegetatively propagated from farmer-produced "seed", long cycle (up to 24 months) and grown with few inputs, a fundamental goal of improvement programs must be varietal stability. The discovery that the sexual stage of the pathogen is common, together with a wide host range, argues that the potential exists for tremendous variability within pathogen populations. Whether within this variability are found high levels of pathogenic specialization becomes of critical concern to breeding programs, since most evaluations for SED disease resistance are carried out at only one site.


Experimental

Several experiments were conducted to test the influence of removing stem cuticle of young cassava plants on subsequent level of disease. Immediately prior to inoculation, stems of plants of cultivars ranging from highly susceptible to highly resistant were subjected to gentle abrasion by a water-soaked cotton swab. This treatment has been found to remove stem culture with minimal damage to underlying tissue. Alternatively, one half of a stem was treated to remove the cuticle while one

half was left with cuticle intact. In all experiments an
equal number of treated and untreated plants were used. Stem
cuticle thickness of young tissue from plants growing in a
heavy SED region (Carimagua Station, Meta, Colombia).was mea-
sured and level of SED on the cultivars taken at the time of
tissue collection.

Cross inoculation studes were conducted using 30 isolates
of diverse geographical origin and over 60 cassava cultivars.
Space limitations permitted only five to six cultivars to be
inoculated wit 10-11 isolates in all possible combinations at
any one time. Level of disease was determined after 10 days,
and was measured as the number of internodes involved (record-
ed as continuous variable) and the percent of affected stem
area directly involved with lesions.

Data from the inoculations were analyzed using a two-way
analysis of variance with the primary interest being signifi-
cant cultivar x isolate interactions. Cultivar x isolate mean
tables were inspected for suspicious interactions when signi-
ficant or near significant F-rations were calculated for cul-
tivar-isolate interactions. Cultivars and isolates involved
in relatively strong interactions were included for repeat
experiments to test the stability of the interactions.


Findings

For all cultivars, regardless of known field susceptibil-
ity, disruption of stem cuticle significantly increased the
amount of disease on the treated stems compared to the untreat-
ed stems. However, susceptible cultivars always remained more
susceptible than resistant cultivars. Thus stem cutivle is
not a primary determinant of resistance. No correlation was
found to become resistant with age. Stem tissues of all culti-
vars, regardless of their level of resistance (or susceptibil-
ity), became completely resistant after about 10 days. This
resistance is unaffected by cuticle removal, and its mechanism
is unknown. Removal of cuticle increased the length of diseas-
ed stem tissue, thus it is believed that cuticle acts as a de-
fensive barrier over susceptible juvenile tissue until the age-
related mechanism develops. Cuticle probably acts simply by
reventing the inoculum from adhering to the stem.

Two-way analysis of variance of the results of the inocu-
lations, evaluated as number of infected internodes and percent
susceptible area diseased, revealed significant cultivar x iso-
late interactions for most of the inoculations using the isola-
tes and cultivars selected from the initial group by their per-
formance in the preliminary experiments. Inspection of the re-
sults showed several isolates that were commonly involved in
the interactions, while others showed no specific interaction

with any cultivars used in these experiments. Likewise, some cultivars showed no evidence for specific interaction with he isolates used, while others did.

In light of the significant cultivar interactions, it is not appropriate to consider grand means as reflections of differences in virulence or resistance for the isolates and cultivars. Several isolates consistently had the lowest mean disease levels over all cultivars in different experiments. However, examinations of the mean tables revealed that this was usually because one or two cultivars behaved as though they were differentially resistant to these isolates, lowering the overall isolate mean. Other cultivars were as susceptible to these "less virulent" isolates as they were to the "more virulent" isolates. Thus, while there was some trend indicative of differences in virulence it was not strong.

While high levels of physiological resistance to all isolates was encountered in stem tissue of some cultivars, none were found to be "immune" or to have a hypersensitive-like response. The leaves of all cultivars showed rather high susceptibility under the experimental conditions. Cultivar x isolate interactions typically were such that the cultivar appeared differentially resistant rather than differentially susceptible. Similarly, interactions were rarely "complete". That is, two isolates causing significantly different amounts of disease on each cultivar tended not to reverse order of virulence on another cultivar. Rather, they would cause equal amounts of disease. Another interesting result was that some cultivars that have a high level of apparently stable field resistance showed significant interactions with some isolates and showed levels of physiological susceptibility comparable to those cultivars very susceptible in the field. The factor other than physiological host-pathogen compatibility appear to be involved in the development of superelongation disease epidemics in the field.

It is important to consider in a technique such as that used here to detect host-isolate interactions that one is simply evaluating one, and the first, exposure of the plant to the pathogen. In the field SED is multicyclic, and the ability of the cultivar to limit subsequent generations may be equally, or more, important that the susceptibility at one, or the first, encounter. Any glasshouse evaluation of resistance must include means, of evaluating this. Additional parameters of evaluation should include incubation and latency periods, final lesion size, sporulation rate, and conidia size.

To evaluate importance of pathogenic specialization phenomenon within the context of host species and cassava breeding programs, it is necessary to determine whether or not the interactions observed are real. Several independent lines of evidence suggest that, although weak and subject to variation,

544

there is specific adaptation of resistance in some cultivars
to virulence factors found in the pathogen population.  First,
in all inoculations the relative response of a cultivar with
known high field susceptibility to the same isolates remained
rather constant.  There were only two isolates showing signi-
ficant differences in their relative virulence on this culti-
var over different inoculations using the standard technique.
These isolates do not enter into evaluations of interactions.
Second, statistically significant interactions were repeatable.
In general, most cultivars used in the detailed experiments
showed interaction with some isolates and these were consist-
ent with earlier observations.  This is to be expected since
most of the cultivars and isolates were selected out of the
preliminary inoculations because they appeared to show speci-
fic interactions.  It is significant that those cultivars
which uniformly showed initial very high susceptibility or
very low susceptibility with no interactions remained stable
in subsequent inoculations over the same as well as other iso-
lates.

Summary of the data in the form of a cultivar x isolate
table is not presented here.  Presentation of the dara in such
a form could be misleading and possibly be interpreted as pro-
viding evidence for "races".  We feel that the relationship be-
tween *E. brasiliensis* and cassava is such that to define "ra-
ces" and "differentials" would impose wholly arbitrary and sim-
plistic limits on a dynamic and fluid system.


ANTRACNOSE (Withere-tip)


This disease has been reported as a disease of cassava in
many countries (Bouriquet, 1946; Vanderweyen, 1962; Affran,
1968; Doku, 1969; CIAT, 1972). but it was generally considered
to be of minor importance, however, it is now known that can
cause severe losses and decrease the quality of stem planting
material.  Sunken leaf-spots about 10 mm diam. and similar to
those caused by *C. henningsii* are produced at the base of lea-
ves which may subsequently die.  Stems may also be attacked
causing a wilt of very young stems and producing cankers on
older ones (Vanderweyen, 1962; Irvine, 1969).  New leaves pro-
duced at the beginning of rainy seasons are reported to be the
most susceptible, and the disease tends to disappear at the ap-
proach of dry seasons (Doku, 1969; Irvine, 1969).  Similarly,
it has been found that artificial inoculations using spore sus-
pensions are only successful when the plants are kept for 60 h
at 100% R.H. (CIAT, 1972).

The causal organism has been variously reported as *Glome-
rella manihotis* Chev., *Colletotrichum manihotis* Henn. (Vander-
weyen, 1962), *Gloesporium manihotis* (Bouriquet, 1946), and

*Glomerella cingulata* (Irvine, 1969). Recent taxonimic studies have determined that *C. gloesporioides*, *C. Glisosporiodis* fs. *manihotis* and *C. graminicola* are pathogens of cassava that induce the anthacnose.

A stem anthracnose caused by a *Colletotrichum* sp has been reported in Nigeria (IIta, 1972). On young green stems oval, pale brown, shallow depressions bearing a spot of normal green tissue in the centre are formed. On the bark of woody stems it produces raised, round, stringy lesions which develop into deep cankers and may distort the stem. The disease severely decreases fresh quality of planting material.

## LEAF AND STEM RUST SPOT

This has been reported in Brazil (Amaral, 1942a; Normanha, 1970) and appears at the end of dry periods causing a kind of witches broom at the apex of the stems (Normanha, 1970). In Colombia leaf, petiole and stem pustules have been observed on cassava growing in cool upland regions, but Normanha (1970) states that the disease is rarely serious except ocassionally in the north-east of Brazil during the hot, dry season. It has been also reported in south Ecuador causing serious epidemics. Six different species all belonging to the *Uromyces* genus have been reported afecting Euphorbia species.

### Stem-rot disease

Three stem-rot diseases have been observed on stems stored for planting (CIAT, 1972). (The storage of planting material is necessary in those areas which do not have a continuous growing season). At CIAT these diseases greatly reduce viability, directly and also indirectly through increased dessication of the cuttings. About 18% of apparently disease-free planting material was discarded because of disease after fifty days storage at ambient conditions in the laboratory. To reduce loss of viability because of desiccation stem cuttings were dipped in paraffin wax which, however, considerably increased disease incidence.

While three distinct diseases have been recognised, it is not always possible to distinguish among them. Macroscopically, these diseases may appear similar, particularly during their early stages of development. Furthermore, more than one of the rot producing organisms may be present.

## Glomerella Stem-rot

This disease is the most common stem-rot of stored cassa-
va cuttings. The same fungus also infects old stem debris
left in cassava plantations. The rot first appears at the cut
ends and gradually spreads throughout the cuttings. A black
discolouration of the vascular strands precedes the development
of surface blisters which later rupture the epidermis exposing
black groups of perithecia in a well developed stroma (Fig.5).

According to CMI the causal organism appears to fall with-
in the general broad concept of *Glomerella cingulata* (Stonem.)
Spauld, Schrenk. Ascospores are hyaline, one-celled, and
slightly curved. Infection is thought to occur through wounds
and to be favoured by high relative humidities.

## Botryodiplodia Stem-rot

This disease has been found infecting stored stem cuttings
and old stem debris in the field but is much less common than
Glomerella stem-rot. The disease characteristically shows dis-
colouration and necrosis of the vascular strands spreading
outwards from wounded parts of the stem. Blisters are produced
on the epidermis beneath which the internal infected tissues
appear dark brown or black. These blisters rupture to reveal
masses of black confluent pycnidia.

According to CMI the causal agent of the disease is *Botry-
odiplodia theobromae* Pat. In both host and artificial culture
this organism produces black mycelium and pichidia which are
erumpent, confluent, stromatic and ostiolate. The conidiopho-
res are short and simple and produce dark conidia that are two-
celled at maturity and slightly elongate. Infection is thought
to occur through wounds and to be favoured by high relative hu-
midities.

## An Unidentified Stem-rot

A third stem-rot is caused by an unidentified basidiomyce-
te. This disease, although relatively uncommon has been observ-
ed on old, mature and young stem pieces both in the field and
in storage. Infected stem pieces are necrosed showing slight
brown discolouration and at time a white mycelium can be observ-
ed growing beneath the epidermis. Under certain humid condi-
tions small white cup-shaped basidiocarps arise from the epi-
dermis of heavily infected cuttings. The identification of
this basidiomycete and the importance of all three stem-rots
need to be investigated.

Other woody pathogens reported in the section on root-rots

Fig. 5   Glomerella stem-rot (Glomerella cingulata). Pieces of stem
showing eruptive blisters and groups of black perithecia.

infect the stem bases of cassava plants and may also be involved in losses of stored stems.

The occurrence of these stem-rots is favoured by high relative humidity; infection probably occurs through wounds. Stem material intended for planting purposes should be handled with extreme care and carefully selected so that only cuttings with viable buds are used. The use of fungicides and surface sterilants to reduce the incidence of these diseases is being investigated.


Root-rot Diseases

Root-rot diseases of cassava are important in areas with badly drained soils or during periods of excessive rainfall. Many of these pathogens induce damping-off during the early stages of plant growth and rot of the thickened roots during later stages. Although several root-rot diseases have been reported, few details are available and the symptoms described for each disease are similar. Generally, infection of young plants causes damping-off white infection of older tissues results in a partial or complete wilting and a soft or dry-rot of the thickened roots. Frequently, following infection by one or several pathogens, a broad spectrum of weak pathogens and/or saprophytes invade the diseased roots, masking the identity of the inicial causal agent and causing all root-rots to appear similar. Several of these diseases caused by woody pathogens are more commonly found when cassava is planted following a woody crop, such as coffee, or immediately after forest clearance. Root-rots of the growing crop are caused by both fungi and bacteria; there could be grown in root and dry root rots.


1. Soft Root-rot.- They are commonly induced by *Phytophtora drechsleri* and *Pythium* spp. during the rainy season in heavely, poorly drained soils with a high organic matter content and above 6.0. Phytophtora root rot has been reported infecting cassava plantations in 3oth )Fassi, 1957) and tropical America (Vanderweyen, 1962; Muller and Carneiro, 1970) where it has caused losses of up to 80%.

Pathogen attacks mature or young plants, frequently near drainage ditches, causing sudden wilting and a severe soft rot of the swollen roots. Initially infected young roots snow spreading water-soaked patches which later turn brown (Fig. 6). Infected swollen roots frequently exude a pungent watery liquid and eventually decompose completely in the soil.

Three *Phytophthora* spp. have been reported as inducing disease in cassava roots; *P. drechsleri* in Brazil (Muller and Carneiro, 1970) and Colombia (CIAT, 1972), and *P. erytrosepti-*

*ea* and *P. cryptogea* Path, in tropical Agrica (Fassi, 1957; Vanderweyen, 1962). These fungi which also cause root-rots of several other plant species are well known.



FIGURE 6.    PHYTOPHTORA ROOT-ROT (*Phytophtora dreschleri*). ROOT-ROT OF YOUNG PLANTS TOGETHER WITH AND UN-INOCULATED CONTROL

The selection of suitable soil for cultivating cassava, the installation of a good drainage system, planting on ridges, maintaining the soil clean of debris, rotating cassava with cereals or stopping planting cassava for a period of no less than six months if indices of root rot in the plantation are higher than 3%, and using resistant clones are effective control measures to soft root rotters.

2. <u>Dry root rots</u>.- Dry roots are induced by various pathogens such as *Rosellinia* necatrix, *Armirariella mellea*, *Rigidoporus lignosus*, *Diplodia manihotis* and other root pathogens. A summarized information is following.

a. Diplodia root rot .- This disease is induced by *D. manihotis* which has caused considerable losses in cassava plantations in Africa and Latin America.

It has two stages: (1) root rot which is initiated when soils are infested or when cuttings taken from diseased plants are used. Its symptom, similar to that induced by root pathogens, consist in sudden death of the whole plant caused by root deterioration; and (2) stem rot caused by the systemic invasion of the fungus from the roots or through wounds. The fungus produces fruiting bodies (pycnidia), whose fruitifications (pycnio-spores) germinate and penetrate into the aerial part of the plant through any wound. Pynidia are black, pear-shaped, and found mainly on the epidermis, where they are readily visible with a magnifying glass. Symptoms at this stage are characterized by necrosis of the vascular system (the phloem, initially), rupture of the epidermis with gum exudation, partial or total wilting and dieback. These symptoms are very similar to those caused by *X. campestris* pv. *manihotis*), but they differ in that *D. manihotis* produces a large amount of pycnidia in the affected part. The pathogen is disseminated over long distances by the use of cuttings taken from infected plantations and, within the same plot, by the wind and rain carrying the fructifications of the fungus, infested tools, irrigation water and by cultural practices.

A satisfactory control of the disease has been obtained by rotation with non-susceptible crops (maize, sorghum, etc) whenever the infection reaches more than 3%; using planting material taken from healthy plots and treating them with a fungicide mixture (protectant-systemic); desinfesting the tools and selecting for resistant clones.

b. White thread disease.- This is the most widespread and serious root disease of cassava in Africa where its appearance on swollen roots is sometimes taken as an indication of the maturity of the crop. Although this disease is known in Latin America it is not of major importance there at present. The disease is recognised by a white mycelial mat under the bark of swollen roots and by the presence of white cotton-like mycelial threads coating part of all of the exterior or infected roots up to the stem base. Internal infected tissues of swollen roots appear dry and have a characteristic rooting wood odour. Ocassionally young plants are infected resulting in a sudden wilt and defoliation, all the roots being necrosed. The causal organism of the disease is *Fomes lignosus* (Klot.) Bres (Vanderweyen, 1962; Affran, 1968; Doku, 1969; Jennings, 1970; IITA, 1972), a basidiomycete belonging to the *Polyoiraceae*.

c. Rosellinia root-rot.- This disease has been reported from many cassava regions with wet soils which are high in organic matter, and most frequently where cassava is grown following a woody or forest crop (Drummong and Goncalves, 1946; Castaño, 1953; Viegas, 1955). The disease has also been named "black-rot" on account of the characteristic black discolouration and cankers on portions of infected plants below the ground. In the early stage of infection white rhizomorphs that eventually turn black cover root surfaces. Internally, the infected tissues of swollen roots become slightly discoloured and exude a watery liquid when squeezed. Black mycelial strands penetrate into and grow throughout the infected tissues and small cavities containing whitish mycelium may be formed (Fig. 7) infected swollen roots have a characteristic rooting wood odour. There are no reports that young plants are infected by this disease, but care should be taken to select planting material that does not come from infected plants.



FIGURE 7. ROSELLINIA ROOT-ROT (*Rosellinia necatrix*). ROOT-ROT OF SWOLLEN ROOTS.

*Rosellinia necatrix* (Hartig). Berl, the perithecial stage of *Dematophora necatrix* is the causal agent (Castaño, 1953; Viegas, 1955). This fungus induces root-rots in other woody and herbaceous plants (Castaño, 1953; Viegas, 1955; Alexopoulus 1962) and is adequately described in the literature. Little information is available, however, about the epidemiology of this fungus on cassava, the sexual stage is thought to occur rarely (Castaño, 1953; Alexopoulus, 1962).

d. Sclerotium root rot.- This root-rot is commonly observed on young cuttings, on more mature roots, and as a coating on swollen roots of cassava in Latin America (Viegas, 1943a, 1943b; Ferdinando *et al*, 1968; Martin, 1970; CIAT, 1972). White mycelium radiates into the soil from infected roots or stem bases. This mycelium may on occasions penetrate the roots through wounds and cause rotting. While young plants are rarely killed by this disease considerable root necrosis may occur.

The disease is caused by *Sclerotium rolfsii* Sacc., a common but weak soil pathogen which has cottony-white mycelium and characteristically forms numerous rounded sclerotia both on the host and in artificial culture.

e. Root smallpox disease.- The disease is induced by indirect damage due to localized lesions that can be caused by subterranean sucking insects and other agents. This disease has been observed in Colombia, Panama and Mexico in association with the subterranean sucking insect *Cyrtomemus bergi* (Cydnidae), causal agent of the initial lesion; however, other agents causing similar lesions (i.e., nematodes) can also induce this disease. While sucking, the insect wounds with the stylet the epidermis and cortical zone of the root. The microorganisms penetratin through these wounds cause localized cortical and epidermal rots, due to the degradation of cortical tissues. Lesions are light to dark-brown in color, limited by healthy areas, and show fermentation of tissues invaded by microorganisms. Symptoms, visible at harvesting, lessen root quality considerably.

To solve this problem, it is necessary to control the subterranean insect or any other wound-causing agent. Crop rotation with non-susceptible plants (legumes as Crotalaria spp). is effective as well as insecticide treatments to infested soils. Bitter clones are resistant.

f. Other root-rot diseases.- Several fungi may induce damping-off and root-rots of cassava, but little or no information is available regarding their occurrence or importance. *Armillariella mellea* Vahl. is reported associated with a stem-

base and root-rot of mature plants (Vanderweyen, 1962; Arrau-
deau, 1967; CIAT, 1972). *Pheolus manihotis* (Heim, 1931), *La-
siodiplodia theorbromae* Griff, *et* Mubl. (Vanderweyen, 1962),
*Pythium* sp., *Fusarium* sp. (CIAT, 1972), *Clitocybe tabescens*
(Arraudeau, 1967), *Sphaceloma manihoticola* B. *et* Jenkins (Bi-
tancourt and Jenkins, 1950) *Rhizopues* spp. (Majumder *et al*
1956), Rhizoctonia sp. (Goncalves and Franco, 1941), and *As-
pergillus* spp. (Clerk and Caurie, 1968) are all reported as
causing rooting of cassava roots.

Secies of *Bacillus, Erwinia,* and *Corynebacterium* have been
reported as inducing soft-rots and/or fermentations in swollen
roots (Collard, 1963, Akinrele, 1964; Averre, 1967). The symp-
toms of these soft-rots are similar and are frequently accompa-
nied by fermentations. The bacteria are throught to enter swol-
len roots through wounds induced by man during cultural opera-
tions, by animals or insects, or by fungi, and are frequently
accompanied by many other saprohytic micro-organisms.

Pathogenic species of the genus *Bacillus* form spores in
most media containing sugar. *Erwinia* spp. can be isolated and
distinguished using the Kado and Heskett medium (1970); their
pectinase activity as detected on sodium-polypectate medium,
and their peritrichous flagella. *Corynebacterium* spp. can
also be isolated and distinguished by the use of selective me-
dia (Kado and Heskett, 1970), pleomorphism of their cells, and
thei gram-positive reaction.

Cassava blight bacteria may also induce necrosis, discolo-
uration , and dry-rot of the vascular tissues of swollen roots
(Lozano, 1972a; Lozano and Sequeira, 1973b).

Core root-rot is a physiological disorder that causes da-
mage to swollen roots in tropical Africa (Barat *et al*,1959;
Averre, 1967). It also occurs in wet, badly drained soils
where it takes the form of a dry internal necrosis, irregular-
ly spreading out from the centr into the cortical tissues. This
disorder is observed in only 10-20% of the roots of an infect-
ed plant, and only the larger thicker roots are though to be
susceptible.

While it is not fully understood whether the rapid dete-
rioration of cassava roots that occurs after harvest is the re-
sult of physiological or pathological causes, or a combination
of both, numerous micro-organisms have been isolated from de-
teriorated roots. Several of these are known to cause disco-
loration and rotting. The literature relevant to the posthar-
vest deterioration of cassava roots has been reviewed by Ingram
and Humphries (1972). The important role of mechanical damage
in deterioration and its possible control by wound healing and
curing has been described by Booth (1972, 1973a, 1973b). Re-
cent developments on root storage show that the problem can be

solved by controlling the physiological deterioration maintaining the roots at high RH and controlling the microbial deterioration with no poison fungicides.

THE TREAT OF INTRODUCING CASSAVA DISEASES AND PESTS ON PROPAGATION MATERIAL

*Manihot esculenta* Crantz (cassava, manioc, mandioca, yuca or tapioca) probably originated in northern South America (Brazil, Guyana) with a secondary center of origin in Mesoamerica (mexico, Guatemala, Honduras)(Rogers, 1963). Its present distribution is world-wide: between latitudes 30° north and 30° south, at elevations ranging from sea level to more than 6500 feet (Jones, 1959; Rogers, 1963). This ecological zone, the "cassava belt", coincides roughly with the FAO Economic Class 2, or less developed countries. This belt accounts for 46 percent of the world's arable land, 46 percent of the world's population and only 13 percent of the world' Gross Domestic Product (FAO, 1971 and 1972). In 1971 (FAO, 1972), world production of cassava was estimated at 92.2 million tons from 9.8 million ha, giving an average yield of 9.4 tons/ha.

The cassava is one of the major sources of carbohydrate for more than 300 million people living at close to subsistence levels in tropical areas. Fresh and dried roots, as well as leaves, are used either as human or animal feed. Fifty-five million tons are consumed by humans, and recent projections estimate that by 1980 consumption will rise to about 71 million tons (Phillips, 1974). Commercial products include tapioca, adhesives and starch for sizing and laundry purposes.

Cassava cultivars are important as sources of energy: The root is 30-40 percent dry matter, 90 percent of which is in the form of soluble carbohydrates; but there are relatively small amounts of crude protein (averaging 1 to 2 percent of dry matter, fats, vitamins and minerals (Barrios and Bressani, 1967). However, the protein content of young cassava tops (leaves) is around 20 percent (Cock, personal communication). The amino acid content of cassava roots is similar to that of corn, with low methionine, high threonine, and intermediate levels of lysine and other amino acids (Olson *et al*, 1969).

Prior to 1971, limited knowledge was available on all aspects of cassava production. In general, the literature implies that diseases and pests were not important in cassava although information of losses due to these was scarce and limited. A large proportion of these publications mention the existence of different pathogens, but few deal with their importance, ecology or control. In the las four years, two inter-

national institutions (Centro Internacional de Agricultura Tropical and International Institute for Tropical Agriculture) have established an international network of cassava researchers somewhat analogous to those already existing for whea- and rice. Furthermore, national institutes and organization, such as the Central Tuber Research Institute in India, have now given high priority to cassava research programs. As a consequence, cassava cultivation has been increasing dramatically during recent years, and it is anticipated it will continue to increase further in the near future.

Cassava is propagated asexually by planting stem pieces as seed. To satisfy the need for a continuous planting program to supply a steady market, propagating material is usually produced by the farmers themselves, who must often introduce material from neighboring regions because planting stakes cannot be stored for an extended length of time. To obtain new cultivars with promising characteristics, to introduce or to increase a cultivar with desirable characteristics, farmers, institutions and governments have often interchanged cassava planting material. This interchange of material appears to have increased during the last few years due to the expansion of cassava cultivation.

The efforts to increase yield and production are threatened by the underestimation of the importance of diseases and insects in cassava and the need for effective quarantine measures. This paper discusses some problems arising from the international transfer of planting material.

GEOGRAPHIC DISTRIBUTION

Cassava is affefted by more than 25 pathogens including fungi, bacteria, viruses, virus-like diseases and mycoplasma (Lozano and Booth, 1974). More than 90 species of insects and 6 species of mites have been recorded as pests of cassava (Montaldo, 1967), and several nematode species are cassava parasites even though the literature on this is sparse. These organisms can cause considerable losses and, at times, are limiting factors in crop production. The potential danger of introducing some of these organisms into uningested areas is serious.

Except for *Cercospora henningsii* and *C. vicosae*, which have been observed in almost all warm cassava-growing areas of the world, cassava pathogens appear to be confined to specific geographical zones; i.e., continents or ecological regions within the continents. Some of these pathogens, such as *C. caribaea* and *Phoma* sp. occur endemically in tropical America in those cool cassava-growing areas where the average maximum temperature is below 20°C or in the warner regions, during the

556

coolest periodsof the year (Lozano and Booth, 1974; CIAT, 1974). Other pathogens occurring in the Americas, such as *Sphaceloma* sp. and *Colletotrichum gloesporoides* fs. *manihotis* induce epiphytotics in warm cassava-growing areas during the rainy season (Lozano and Booth, 1974; Krausz, 1975); or, as in the case of *Oidium manihotis*, during the dry season. Root rot fungi of cassava are commonly present around the world since they are also pathogens of perennial and forest crops; their incidence seems to be related to edaphic and cultural conditions as well.

In the Americas (Brazil, Venezuela and Mexico) there is a low incidence of cassava mycoplasm and virus diseases which occur independently of environmental and edaphic conditions. In contrast, the African mosaic disease of cassava is observed in almost all cassava plantings in tropical Africa, primarily because it is disseminated by insects (*Bemisia* spp.). A similar disease, also disseminated by *Bemisia* spp., is found endemically in India (Lozano, 1972).

Among the bacterial pathogens, *Xanthomonas cassavae* appears to be restricted to Africa (Dowson, 1957; Wiehe and Dowson, 1953). The causal agent of cassava bacterial blight, *X. manihotis* is present in America; but it has been found in Africa and Asia (Thailand and Malaysia), causing severe epiphytotics (Lozano, 1975). Even though *Pseudomonas solanacearum* has been reported as a cassava pathogen (Kelman, 1953; Castaño, 1972) and its different races are found in many cassava-growing areas, there is no conclusive evidence that this bacterial species is a cassava pathogen. A new bacterial species recently found in association with certain stemborer insects of cassava (Lozano and Bellotti, unpublished data) is present in the Americas, but its distribution and importance are unknown.

Mites appear to be a universal pest of cassava. The *Tetranychus* mite (*T. urticae*) is recorded as a pest in Africa, Asia and the Americas, while the *Mononychellus* mite ( *M. tanojira*) is reported in the Americas and Africa. Thrips, whiteflies, stemborers, leaf-cutter ants and cutworms attack cassava in Africa and the Americas. The cassava hornworm (*Erinnyis ello*) shoot flies (*Silva pendula*, fruit flies (*Anastrepha pickeli* and *A. manihoti*), and gall midges (*Cecidomya* sp.) attack cassava only in the Americas. Grasshopper feeding on cassava is restricted to Africa while white grubs, termites and scale insects are reported from Africa, Asia and the Americas (Schoonhoven and Bellotti, 1975).

# DISSEMINATION OF DISEASES AND PESTS

Based on the above general distribution of cassava pathogens, any movement of cassava planting material represents a serious risk of diseminating these disease and pests. The most important pathogenic agents in cassava - for example, those that cause cassava bacterial blight and African mosaic disease, vascular pathogens, and superelongation disease, an epidermal and cortical pathogen- are disseminated unsuspectingly through the use of diseased stalks as planting material (Lozano, 1972; Lozano and Booth, 1974; Krausz, 1975).

For example, the causal agent of cassava bacterial blight is restricted to the host xylem tissue in mature stems because the bacteria is unable to degrade lignified tissues (Takatsu and Lozano, 1975; Lozano and Sequeira, 1974). Therefore, the presence of bacteria in these tissues, which are normally used for plant propagation, is very difficult to detect. Also the severity of the disease is considerably reduced during the dry periods of the year; thus visual selection of healthy material for propagation from an infected plant is sometimes impossible. Considering its potential of spreading by rain water, tools, unhealthy planting material (Lozano and Sequeira, 1974), infested soil and insects (CIAT, 1974), the rapid dispersion from a few unhealthy plants in a plot can occur in relatively short periods of time (Lozano and Sequeira, 1974), causing economic losses of more than 50 percent (Lozano, 1975). Considering that (a) cassava originated in the Americas; (b) *Xanthomonas manihotis* is specific to *Manihot* spp.; and (c) that cultural, morhological, physiological and serological studies of isolates from Africa, Asia and America show similar species characteristics (CIAT, 1975; Lozano, 1975), it is concluded that this pathogen was probably introduced from America to Africa and Asia by the introduction of infected plant material. This introduction caused serious economic damage in Nigerian and Zairo cassava-growin areas (Maraite and Meyer, 1975) and poses a threat to Thailand's and Malaysia's cassava production in the near future.

The estraordinary severity, ability to be disseminated and lack of effective control measures make the African mosaic disease of cassava one of the most serious diseases of the crop in the world. Although the disease is not present on the American continent, the vector, *Bemisia* spp., has recently been found (Bellotti, personal communication). Hence, its introduction into America or other uninfected areas represents a most serious threat to these cassava-producing areas. Although the consequences of such an event are unforeseeable, it is known that the disease is capable of reducing production by 20 to 90 percent (Lozano, 1972).

In general, all viruses and mycoplasma of cassava in the Americas invade the vascular system (Costa and Kitajima, 1972) and are disseminated mainly by propagation of vegetative material. Their introduction into uninfected areas within the Americas or other disease-free represents a serious risk. The mycoplasma disease (witches'-broom) has recently been reported in the Ivory Coast (Dubern, 1972), possibly introduced to Africa by infected propagative material, since there were no previous reports of this disease there. The brown streak virus is another disease originating in Africa that can be introduced into the Americas through vegetative material (Lozano, 1972; Lozano and Booth, 1974).

Little is known about the dissemination of fungal pathogenic agents of cassava through infected stalks, with the exception of the causal agent of the superelongation disease (*Spahceloma* sp.). This pathogen grows into the cortex and epidermis, producing spores in epidermal cankers which are capable of maintaining enough inoculum for secondary infections. Its ability to sporulate and to be disseminated by wind flow during the rainy season appears to be responsible for the observed spread of the disease in cassava-growin areas (Colombia, Venezuela and Panama) (Lozano and Booth, 1973; Krausz, 1975). If this pathogen is introduced to other countries or continents, it is suspected that a similar rapid spread over long distances will occur in a relatively short period of time (Krausz, 1975).

Because of their possible adhesion to the epidermis of the stalks, the spores of other fungal organisms, particularly those that attack the stem (*Glomerella* sp, *Fusarium* sp., *Sclerotium rolfiss*, *Botrydiplodia*, sp., etc), could also be introduced into other regions with material for propagation.

Except for cassava bacterial blight (Lozano, 1975), the African mosaic disease (Lozano, 1972) and the common mosaic virus (Costa and Kitajima, 1972), which appear to be specific to *Manihot* spp., no information is available on host range of other cassava pathogens or pests. However, propagating material of species belonging to *Euphorbiaceae* (forest or ornamental crops) also represents a serious risk of disseminating cassava diseases. This risk is emphasized by the recent finging that a *Sphaceloma* sp. found on *Poinsettia* sp. is also pathogenic to cassava.

The possible dissemination of the pathogens of cassava through true seed is unknown, except for cassava bacterial blight which is not seed transmitted (CIAT, 1974). Although the risk of dissemination through the use of true seed appears limited in cassava, there are many examples in literature of its occurrence in other crops, especially for viral agents. Because of this, it is logical to suggest that precautions be observed until convincing studies on the matter prove otherwise.

The dissemination of insect eggs and of mites in vegetative material is more probable than that of larvae and adults. Generally, adults and larvae living on the epidermis of the stem are relatively easy to detect. Nevertheless, stemborer, scale and mite eggs (Bellotti, personal communication) can be disseminated via stem pieces. A recent example of insect dissemination, possibly through the importation of stem pieces for propagation, is that of the introduction of mites into Uganda. This pest was disseminated into western Kenya and Tanzania, causing serious losses for the cassava growers in these areas (Nestel, 1974; Nyiira, 1973).

## GENERAL CONCLUSIONS AND RECOMMENDATIONS

Although the economic effect on yield is unknown, the sanitary condition of the vegetative material used for propagation can become the most important factor in successful cassava cultivation. For instance, it is known that more than 25 percent of the propagation material does not germinate when cassava cuttings are infected with bacterial blight and that losses in germination of cuttings attacked by scale insects (*Aonydomitilus albus*) are often as high as 80 percent (Schoonhoven, personal communication).

Based on the aforementioned considerations, it is concluded that (a) the spread of pests and diseases of cassava through vegetative propagation material represents a serious threat to the crop; (b) strict quarantine provisions are necessary in order to avoid the possible introduction of pathogenic organisms and pests into uninfected areas; (c) more information is needed about the potential damage that many plant pathogens and pests can cause to cassava cultivation; and (d) cassava requires careful selection and treatment of all vegetative material before distribution for experimental or commercial propagation.

Recent research shows that clean vegetative planting material can be produced; thus, it may be possible to eliminate the dissemination of vascular pathogens, such as the causal agents of cassava bacterial blight (Lozano and Wholey, 1974), the American viruses (Lozano, 1972; Costa and Kitajima, 1972), and the superelongation (CIAT, 1974) diseases. Similarly, pests and propagules of pathogens that may be disseminated on the surface of planting material can readily be eliminated through the use of chemicals. The use of tissue culture techniques produces symptom-free material from plants infected with the African mosaic disease (Kartha and Gamborg, 1975); however, it cannot be asserted whether the disease is present in latent form. Nevertheless, the use of these techniques to transfer material within the African continent is suggested.

560

Applying general quarantine principles specifically to cassava, the following recommendations relating to the international movement of cassava planting materials were discussed and suggested at the Workshop for International Exchange and Testing of cassava Germplasm, held at CIAT in February, 1975 (IDRC/CIAT, 1975).

## General Recommendations

1.  The expertise in pest and disease recognition available at CIAT and IITA should be utilized to train national crop protection specialists who could then return to their respective countries and conduct course on pest and disease symptomatology and recognition for quarantine purposes.

2.  It is recommended that the smallest possible amount of planting material be imported; the smaller the amount, the less the chance of its carrying a pathogen or pest. Inspection of this material, as well as postentry quarantine, will be simplified.

3.  The implementation of the recommendations for minimizing the risk of disease and pest introductions is the joint responsibility of the donor and recipient.

4.  These recommendations merely supplement existing quarantine regulations of recipient countries.

## Recommendations Relating to the Movement of Vegetative Propagating material

1.  Material should never be imported from countries where African mosaic diseases and brown streak virus disease are present.

2.  For importations from all other countries, the following procedures are recommended:

a.  In the donor country

1)  Use only select material from a disease-free source.

2)  Treat the material with a combination of fungicide (Thiram or chloroneb) and insectivide (Methamidophos or Carbofuran).

3)  Handle material with extreme care; disinfect and

sterilize all tools and packing materials.

b.  In the recipient countries

1)  Burn on arrival all material which shows pest in-
    festation or disease symptoms.

2)  Retreat the material with fungicide and insecti-
    cide.

3)  Establish the material in an isolated area and
    make regular and thorough plant inspections over
    a one year period.

4)  Burn any of the established plants with pest in-
    festation or disease symptoms not found in the
    country.

3.  In addition to these general recommendations, material
being exported from a country where superelongation is known to
be present should receive a hot water dip (50°C for 30 min.)
(CIAT, 1974).  Countries importing material from countries where
cassava bacterial blight is known to be present should underta-
je shoot-tip indexing within twenty days of germination (Lozano
and Wholey, 1974; Takatsu and Lozano, 1975).

Recommendations Relating to the Movement of True Seeds

1.  In the donor country

a.  Select the seed from disease-free plants.

b.  Select the best-quality seed (visually).

c.  Treat with a fungicide (Thiram) and an insecticide
    (Malathion).

d.  Handle the seed with care and disinfect and sterilize
    handling and packing materials.

2.  In the recipient countries

a.  Burn on arrival pest-infested or obviously diseased
    seed.

b.  Establish the material in an isolated area and make
    regular and thorough plant inspections over a one-year
    period.

c.  Burn any plant with pest infestations or disease symp-

562

toms not found in the country.

## Proposals for Future Consideration

1.  Consideration should be giben to the establishment of an intermediate quarantine station in a noncassava-producing country or island.

2.  The possible future use of the tissue culture techni- que for quarantine purposes should be examined.  It is consider- ed that the technique could give a large margin of security to the known virus diseases and cassava bacterial blight; never- theless, it is not recommended in the case of the African mo- saic disease since the causal agent of this disease is still unknown.

By following these recommendations, the author considers that the risk of introducing new pathogens and pests into an area could be greatly reduced or eliminated.  In many countries, quarantine regulations are nonexistent and should therefore be imposed; in other countries excessively strict quarantine regulatins have been formulated because of lack of knowledge. From the recommendations presented in this paper, regulations could be formulated that would not only protect countries against the introduction of new diseases and pests but would also give them the advantage of obtaining better genetic mate- rial.


PATHOLOGICAL PROBLEMS OF CASSAVA (*MANIHOT ESCULENTA* CRANTZ)

DISSEMINATED BY SEXUAL OR ASEXUAL PROPAGATED MATERIAL


The interchange of plant genetic materials between and among centers and research institutions is desirable and neces- sary to improve the crop species.  However, such action bears risks relating to the dissemination of plant pathogens and pests affecting the propagative material that is exchanged. The responsibility of such risks should be equally shared by both donors and recipients, but generally it is not always practical.  It should be kept in mind that the probability of disseminating plant pathogens and pests through the interchan- ge of vegetatively propagated materials of crop species is very high.

Cassava (*Manihot esculenta* Crantz), a vegetatively propa- gated crop, has very important pathological and entomological problems which can be disseminated by the exchange of either sexual or asexual propagating materials.  Only recently research on cassava has been taken into consideration by several nation-

al institutions. Thus several pathological and entomological problems of this crop can still be unknown due to lack of sufficient investigation devoted to this crop. In certain cases such as the African cassava mosaic and the frog skin disease the causal agents are still unknown, aggravating the problems. This paper discusses some pathological problems of cassava which could be disseminated by the interchange of propagating materials and suggests some recommendations to minimize the risk of disseminating such agents.

## CASSAVA PATHOGENS DISSEMINATED VIA THE SEXUAL SEED

Cassava pathogens that can be disseminated by the interchange of sexual seeds can be divided in two broad groups: (1) those that infest the seedn and (2) those that infect it.

Information regarding the dissemination of pathogens via the infested cassava does not currently exist in the literature, but the possibility cannot be overlooked. While considering the cassava seeds which are produced in a tricapsular fruit, their infestations may occur after fruit dehiscence, when the seeds are released. If the seeds fall onto the ground, in the field the probability of seed infestation is higher than when the seeds are collected and stored under control conditions. The pathogens of cassava that probably can survive and infest the seeds are those with abundant muscilagenour propagules, such as in the case of *Colletotrichum* spp., *Phoma* spp., *Diplodia* spp., *Xanthomonas campestris* pv. *manihotis*. In many cases the infestation of the storage containers could be much more risky than the seed per se.

In relation to the pathogens which infect the cassava seed only *X. campestris* pv. *manihotis* (causal agent of cassava bacterial blight, CBB)(CIAT, 1981; Elango & Lozano, 1980) and *Colletotrichum* spp. (causal agents of cassava anthracnosis) have been found to infect the cassava seeds. However, considering the limited information available at present, this does not preclude the possibility of other (either virus, bacteria or fungi) pathogens.

A high percentage of sexual seeds collected from CBB-affected plantations are infected with *X. campestris* pv. *manihotis* without showing any visible external symptoms. Howeverm severely infected seeds show deformations, necrotic areas on the cotyledons and endosperm and corrugation of the testa. These seeds have a very low germination capacity. In infected seeds which do not show any symptoms, the bacterial pathogen is generally located in the embryo in a dormant-like stage which is activated soon after germination. The seeds germinate normally but the disease symptoms are visible only along the stem or

564

leaves (CIAT, 1981; Elango & Lozano, 1980).

## PATHOGENS DISSEMINATED THROUGH THE VEGETATIVE PLANTING MATERIAL

The dissemination of cassava pathogens through the vegetative propagated material is much more probable than through the sexual seeds. During the long vegetative cycle of the cassava plant the stem, which is normally used for propagation, is exposed to the infestation/infection by fungal and bacterial pathogens, especially when the plant is grown in an affected area. Similarly, lignified stems ca be invaded by most of the cassava pathogens without showing visible or highly noticeable symptoms (Lozano & Booth, 1974).

Considering the type of invasion and damage caused, cassava pathogens can be classified as localized or systemic.

### Localized Pathogens

These pathogens are unable to invade the plant systematically, thus the damage is always localized to limited areas or portions of the plant. Its presence is characterized by the formation of cankers, galls, necrosis of the epidermal or cortical areas (yellow to black-brown coloured) and deterioration of the pith. These symptoms are in many instances specific to a given causal agent or to a complex induced by several pathogens (such as pith, cortical or epidermal degradations)(Lozano *et al*, 1981).

The most common symptoms caused by localized pathogens are: galls (*Agrobacterium tumefacciens*), cankers (*Sphaceloma manihoticola*), epidermal and cortical ulcers (*Colletotrichum* spp. and *Phoma* spp.), vascular straking (*Diplodia manihotis*, *X. campestris* pv. *manihotis*, *Verticillum* spp.), pith and cortical degradation (*Erwinia carotovora* pv. *carotovora*), bud necrosis (*X. campestris* pv., *manihotis* and *cassavae*) (Lozano *et al*, 1981).

### Systemic Pathogens

These pathogens are able to invade the whole susceptible plant systematically. Generally, a systemic invasion does not produce visible symptoms on the lignified mature stem portions, which makes it almost impossible to identify diseased material. Hpwever, in this case and in relation to the causal agent, symptoms are noticeable on the leaves, on very young unlignified branches or on the root system. Furthermore, it has recently been found that there are some systemic pathogens such as viruses, which do not show any visible symptoms in certain clones

(carriers) while in others show mosaic, stunting, reduction of vigor and yield. From a quarantine point of view these types of pathogen are very important and merit special attention. The following systemic pathogens can be disseminated by the use of infected vegetative material:

1. <u>Fungal Pathogens</u>.- *Diplodia manihotis* is one of the most important pathogens affecting cassava production. This fungus induces vascular straking along the stem resulting in wilting, but epidermal symptoms are only noticeable on the very young portion of the stem, which makes it very difficult to detect diseased vegetative material (CIAT, 1982). A similar syndrome is also noticeable in the case of *Verticillium* spp. infection. *Sphaceloma manihotis* (causal agent of the superelongation disease) is not a systemic pathogen; it infects mainly the stem epidermal tissues causing minute cankers difficult to identify by the naked eye. Its presence on lignified stems in many cases is very difficult to detect.

2. <u>Bacterial Pathogens</u>.- *X. campestris* pv *manihotis*, the causal agent of CBB, is one of the most important pathogens of this crop. The use of infected vegetative planting material taken from diseased plantations has been the cause of diseminating the pathogen over long distances. By this means the pathogen has been introduced into Africa, Asia and to those regions where the pathogen did not exist before. This is due mainly to the inability of the pathogen to produce visible symptoms on lignified stems and its ability to survive for a very long time in the invaded tissues (CIAT, 1974, 1975; Lozano & Sequeira, 1974). Although it is reported that *X. campestris* pv *cassavae* can be disseminated by the use of infected stakes due to its systemic invasion, it still needs confirmation (Maraite, 1978).

3. <u>Viral Pathogens</u>.- Their systemic invasion is such that any part of the affected plant could be infected. Consequently, any vegetative material taken from infected plants for propagation has the risk of being contaminated. As most symptoms caused by these pathogens occur on leaves (mosaic, etc.) or roots (the frog skin disease), the symptomatological identification on vegetative planting material is sometimes very difficult. This is even more difficult in the case of latent infections where there are no symptoms. Their detection could only be possible by serology (which has not been developed yet), bioassays (by grafting highly susceptible clones on testing genotypes)(CIAT, 1982) or by analyzing the proteins using SDS-PAGE (for the frog skin disease)(CIAT, 1982). These techniques are still being investigated and their accuracy efficiency and effectiveness are to be defined. Therefore, the introduction of vegetative propagatin material of cassava should be done only when necessary, considering the risks involved and taking care to use the optimum sanitary and quarantine measures to avoid the introduction and dissemination of viral or virus-like disease of cassava.

# SANITARY MEASURES TO MINIMIZE RISKS OF DISSEMINATION OF CASSAVA PATHOGENS THROUGH PROPAGATIVE MATERIAL

The following sanitary measures, independent of others legally established in any quarantine regulation, could reduce the risk of disseminating cassava pathogens through propagative material of cassava. Their effectiveness depends on the strict application of such measures by both the donor and the recipient (Lozano, 1976).

1. The recipient country or institution must analyze and evaluate carefully the responsibilities of donors as regards complying with established quarantine regulations. Any introduction should only be decided after a careful analysis of the need and genetic advantages for such an introduction.

2. The recipient country should prohibit the introduction of propagating material of cassava from countries or areas where exotic diseases exist. For example, due to the undetermined origin of the African mosaic, vegetative planting material of cassava should not be imported from Africa, India or any other country where the disease is known to be present until their relationship is established with certainty. The importation from these areas of sexual propagating material could be considered, but under very special conditions established after prior consulation with the quarantine officials of the recipient country.

3. The propagating material of cassava should be collected from apparently systemic-disease-free plantations. More than one inspection, during the appropriate time, shoudl be made before collecting such material to determine the apparent sanitary condition of the plantation. Such inspections should be made during the optimum climatic conditions for the disease development; for example, during the middle to the end of the wet seasons for diseases such as CBB, superelongation and *Diplodia* stem rot or during the optimum conditions established for whitefly-transmitted diseases such as low temperature periods for Caribbean mosaic disease. Before collection, the vigorously growing healthy plants should be identified.

4. Sexual propagating material should be collected from apparently healthy mature fruits, before their dehiscence. Seeds on the ground should be discarded. Fruits should be stored dry in paper bags. After their dehiscence, seeds should be selected according to their shape, size and visual sanitary condition (absence of necrotic lesions of the testa), treated with a protectant fungicide (i.e., Tetramethylthiuram disulfide). Treated seeds can then be packed in new bags and sealed. Seeds should have a dry-heat treatment (50 to 60°C) for two weeks

either by the donor or the recipient, but the treatment should
be done only once. The treatment breaks the dormancy and can
eradicate the causal agent of CBB if present (CIAT, 1982).
After this treatment the seed can be planted in ports or seed-
lings beds maintained in appropriate glasshouses for post-qua-
rantine treatments (periodic observations, serological or elec-
trophoretic tests, etc.

5. It is not recommended to introduce or export currings
of cassava from many country or any geographic region. Vegeta-
tive material should be introduced only as meristem cultures,
but only after sufficient tests have been carried out to deter-
mine the sanitary conditions of the introduced material. Meris-
tems should be taken from shoots arising from cuttings taken
from healthy plants whose health has been tested before growing
on plots where plantations are free from frog skin disease, mo-
saics, bud proliferations or stunted plants. It is also suggest-
ed to avoid any thermotherapeutical and chmical treatment which
may incur the risk of inducing viral mutations or viral byotype
selection (CIAT, 1982). Such treatments, however, could be done
for cleaning within an experimental station. As much as possible
introduced material should be absolutely healthy. If the frog
skin disease is present in a region, grafting with a suscepti-
ble variety is advisable as well as a partial electrophoretic
test for introduced plants (CIAT, 1982). If mosaic disease is
present in the region, grafting sensitive varieties with import-
ed material is advisable. Any material suspected should be eli-
minated by autoclave (120° C and 20 lbs of pressure) or burnt.
All introduced material should receive a post-entry quarantine
treatment for at least a period of one year (growing cycle).
During this period, the sanitary conditions of the introduced
materials should be observed carefully and periodically; at
least three periodic bioassays should be carried out in addition
to any other available test which can help in the detection of
systemic diseases of cassava. It should be considered that in
*M. esculenta*, mosaic-carrier varieties exist which do not show
any visible symptoms, but which can easily be affected and be
the focus of dissemination of diseases when introduced into
clean areas. These diseases could be a threat to the regional
varieties and even to other crop species. Lastly, since infor-
mation available on systemic diseases of cassava in relation
to their identification; detection and epidemiology is very li-
mited, the introduction of vegetative material of cassava should
be kept at a minimum and a clone should be imported only when
it is absolutely necessary. Sexual propagating material, un-
doubtedly, is less risky, besides the advantages related to
ease of preparation, storage, shipment and genetic diversity.

# COMPREHENSIVE BREEDING APPROACH TO PEST AND DISEASE PROBLEMS OF CASSAVA.

Cassava (*Manihot esculenta* Crantz) is a vegetatively propagated crop domesticated and improved by traditional growers for more than 4000 years (Leon, 1977). Traditional clones are the result of a slow process of a mature-man system of improvement in which nature has made the crosses and man the evaluation, selection and multiplication. What we have observed in relatively unperturbed systems is a biological stability (relative absence of pest outbreaks and low but stable yields) apparently the result of interaction of adapted local varieties and traditional cultural practices (multispecific or multiclonal plots).

Within regional populations great genetic variation often exists. Commonly, many clones have a degree of resistance to most biotic and physical stresses in the ecosystem where they were selected along with the quality required to fit the socioeconomic needs of the growers

## Cassava Domestication and Selection

*Manihot esculenta* originated in America with a major center of diversity in South America and a secondary center in Guatemala and Mexico (Leon, 1977). It has been disseminated through south Brazil, Paragua, north of Argentina to central Mexico, Cuba, and the Caribbean Islands.

Early plantations were probably isolated, locally by forests and regionally low montains. Growers followed a slash and burn agricultural system in which cassava was planted in association with other crop species. In some areas, notably in Brazil, this system has evolved to a multiclonal monocropping system in which several clones are mixed or planted in close association. Land preparation, weed control and selection of the planting material have become more sophisticated where cassava was domesticated. Many planting systems may be found in a relatively small area, and vary regionally also.

Many cassava varieties produce out-cross seed in the normal cropping time. Mature seeds fall to the ground where they lie dormant. As the land is prepared for further cultivation the trash and weedy vegetation are burned. The heat releases the cassava seed from dormancy and the seeds germinate. In Amazonas and other regions the growers notice and care for the most vigorous seedlings and follow their performance comparing

them with their "parent" varieties.  If the new plant survives (a "what-is-left" integrated evaluation procedure) and if it gives a satisfactory "yield', or if planting material from known cultivars is limiting, stakes from it are used as planting material in the following cycle.  Continued satisfactory performance leads to an increasing contribution of the new type to cassava production.


## Cassava/Ecosystem Relationships

The most commonly encountered description of cassava before the 1970's was as a rustic crop, resistant to almost all biotic and abiotic problems, and particularly well suited to regions with poor soils and prolonged drought (Phillips, 1974).  Treatments of the crop often implied that it was adapted to a wide variety of environments.  However, earlier descriptions really reflect the plasticity of the species rather than of a particular cultivar.

Recent experimental results demonstrate that the impression of a strong cassava-ecosystem interaction of traditional cultivars is correct:


1.   Etiological and epidemiological investigations show that cassava pests (diseases, insects, mites) are not universal. Their presence and incidence are limited by specific climatic and/or edaphic characteristics that restrict them to ecological zones.

2.   When planting regional and introduced genotypes in four edapho-climatic zones and evaluating the most important parameters for cassava production during three consecutive cycles it was found that the local regional varieties generally produced poorly in all other edapho-climatic zones.

3.   Mean reactions of groups of clones from contrasting edapho-climatic zones and from similar edapho-climatic zones, showed that native cultivars in each environment had the highest levels of resistance to the limiting factors existing in each zone (Figure 1).  No cultivars were resistant to the biotic constraints of more than two edapho-climatic zones.  Resistance to the main limiting factors of a given edapho-climatic area is much higher in cultivars from areas similar to the testing site than in those edapho-climatic zones with a substantially different set of limiting factors.
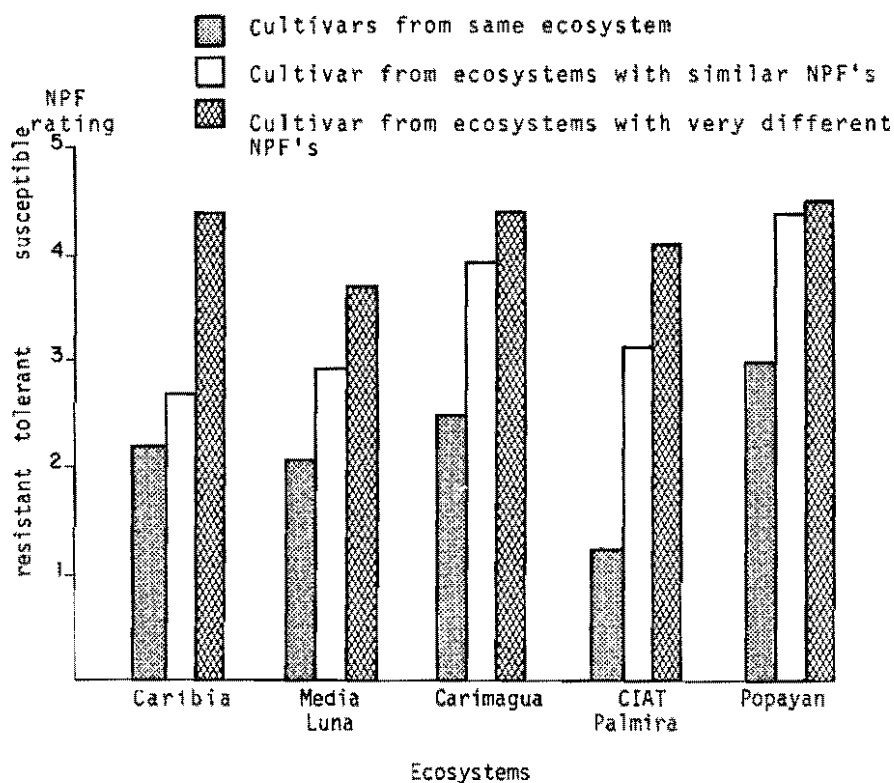
FIGURE 1. MEAN REACTION OF 25 CASSAVA CULTIVARS (COLLECTED OR SELECTED IN FOUR DIFFERENT EDAPHO-CLIMATIC ZONES AND ALL PLANTED ACROSS EDAPHO-CLIMATIC ZONES) TO THE NEGATIVE PRODUCTION FACTORS (NPF's) PRESENT IN EACH SITE.

## Stability in Cassava

Stability is probably best judged by the continued survival of genotypes in a region. Many examples exist in different cassava growing areas: The clone Rayong. I was probably introduced to Thailand earlier than 1960 and it is today grown on over a million hectares (Sinthuprama, 1978); Sta. Catarina was selected in Sao Paulo about 70 years ago and it is currently being planted on more than 300,000 ha in this state and the Campo Cerrado of Brazil; Secundina has been planted for more than 20 years in the north coast of Colombia on approximately 7000 ha; Chiroza has been grown in Caicedonia, Colombia, on more than 6000 ha since 1970. As statistically and edapho-climatic zone where cassava is grown one or more widely stunted native genotypes which have been used for many years are still used.

The stability of yield in nine consecutive-year trials has been recorded in the Popayan area for native and introduced genotypes. In the Carimagua zone, yield, cutting, and starch production and the stability of plant reaction after CBB epidemic infections for several growing cycles has also been recorded for introduced and native clones, but generally the data available on other parameters regarding stability and its complexity on cassava have not been investigated in depth.

## A Program for Genetic Improvement

Based on considerations of the previously described physical, biological and socio-economic parameters, a basis for genetic improvement of cassava is presented. The discussion focuses on the principles of choice of evaluation sites, evaluation methodology, and parameters of evaluation.

## Evaluation Sites

The number of evaluation sites necessary in a breeding program depends upon diversity of the target area, and the breeder's ability to select in any gives site for performance in a specified region. In general terms, the evaluation sites should be where soil characteristics (pH, structure, fertility) and climate (rainfall distribution, relative humidity, temperature ranges and photoperiod) are similar to these of the target area. The number of evaluation sites must necessarily be limited by what is practically and economically feasible for a program to manage.

The biological and physical stresses or constraints to production of each edapho-climatic zone are often multiple and complex. To select genotypes with the widest possible adapta-

tion to different constraints within a region, the selection site should ideally include a wide range of stress conditions, in moderate to high levels, and with a degree of season to season repeatability.

## An Evaluation Methodology

Evaluation should permit selection of genotypes with durable integrated resistance to most constraints in the target production area. On this basis, ideally, select under field conditions, where stress balance factors provide opportunity for simultaneous considerations of various factors, resulting in an integrated resistance. Artificial inoculations or special cultural practices may be useful to increase intensity or uniformity of given constraints, or even to decrease the intensity if a stress factor appears to have potential of masking all genetic differences in the material being evaluated due to its intensity.

Selection should include periodic evaluations of each constraint during the periods of the growth cycle in which it is expressed (e.g., diseases during rainy periods; insects and mites during dry periods). The durability of the resistance of selected material can be partially confirmed by continuous evaluations during several growing cycles, where planting material is produced in situ from the previous cycle.

Finally, some integrated measure of adaptation/resistance in the edapho-climatic zone is more important than the individual disease or insect evaluations. The integrated measure may be a general evaluation of plant health for the root growth, combined with root yield and quality. Including standard local and selected checks permits rational decisions about relative performance of new materials.

## Parameters of Evaluation

The following parameters of evaluation have been taken into consideration in CIAT's Cassava Program. Some have been described previously (Nestel and MacIntyre, 1975).

a. Germination.- Record simply by counting number of plants one month after planting.

b. Vigor.- Vigor is evaluated subjectively and relative to the particular     with reference to standard check varieties. A vigor rating is made from     5 months after planting.

c. __Plant Type__.- The evaluation of plant type is divided
into three components: number of levels of branching, height of
first branch, and plant height.

d. __Leaf area__.- Leaf area index of about 3.0 has been de-
fined as near optimum for cassava (Cock, 1976). Because measure
of leaf area is impractical for evaluation of large numbers of
genotypes, a simple measure of the length of stems maintaining
foliage is used during early evaluation stages to give some idea
of the potential of a clone for continued photosynthesis up to
the end of the growing cycle.

e. __Disease, Insect,and Mite Resistance__.- Evaluations are
based on a damage rating scale, closely related to the level of
genetic resistance.

Most appropriate planting time is one which corresponds to
that most commonly used by farmers in the target region. Thus,
the balance of disease and pest pressure under which evaluation
is done will be similar to that under commercial conditions.
If the crop is commercially planted during different times of
the year, the selection program should conform.

f. __Yield and Harvest Index__.- A generalization under high
productivity environments, select for high harvest index in
early selection stages, low productivity environments, select
for yield itself, along with reasonable harvest index.

g. __Yield of Planting Materials__.- Stem piece (cuttings)
yield and quality are important for productivity and durability
of genotypes so these should be quantified during evaluation.

h. __Root Quality__.- Quality of roots may be critical to
acceptability of a variety intended for human consumption. Qua-
lity is normally less critical for industrial uses.

### 1. Starch Content and Quality

Yield of the crop is appropriately expressed either as dry
matter or starch production, the two being closely correlated.

### 2. Pre-Harvest Root Rot

A simple measure of percentage rotted roots at harvest can
distinguish varietal differences where environmental conditions
permit moderate expression of root rot.

### 3. Post-Harvest Root Deterioration

An evaluation procedure for physiological deterioration
involves scoring 15 cm root pieces after 3 days of storage (CIAT,

1979), with a large number of replicates. The combination of physiological and microbial deterioration can be evaluated after 1 or 2 weeks of storage.

### 4. HCN Content

A rapid picric acid determination gives a good general indication of HCN presence in the roots and is useful when many genotypes are to be evaluated.

### 5. Cooking Quality

Taste, texture, bitterness and fiber can be evaluated subjectively after cooking.


## INTEGRATED CONTROL OF DISEASES AND PESTS OF CASSAVA

Yield stability in any crop is dependent upon the use of ecologically adapted varieties, the employment of appropriate agronomic or cultural practices, and a sound integrated control program for diseases and pests. Because cassava has a long vegetative cycle, is propagated using stakes, and is cultivated primarily under traditional agricultural systems, it is important that an integrated pest-control program be based on cultural practices, biological control, and varietal resistance.

There are numerous cultural practices that aid in the control of insects and diseases. Uniform cultural practices cannot be recommended across all cassava growing areas; they should be adapted to the specific characteristics of each ecosystem. Some cultural practices that can reduce pest and disease stress include proper soil preparation, the use of clean, high-quality planting material, good weed control, removal and destruction of infected plant material and plant debris, crop relation, intercropping cassava with other crops, well planned spacing of plants, proper fertilization, and strict quarantine regulations.

The long production cycle of cassava makes chemical control of pest uneconomical. An integrated control program should include sound biological control practices and the use of resistant varieties. An inventory of beneficial insects and microorganisms of cassava pests should be made. Programs for the mass rearing and release of beneficial insects or the introduction of new, more beneficial species should be initiated. The utilization of varieties resistant to the negative production factors of a given ecosystem is important in the control of pests and diseases and will ensure yield stability and satisfactory production.

Most agricultural research is directed toward the investigation of a specific factor or set of factors related to the production system of different crop species. The results of this research are rarely integrated in a logistic production package. More recently, research has been oriented on a commodity basis, making the integration of scientific teams to study one crop appear more reasonable; thus scientists can develop broader concepts of the crop and its problems, leading to more applied results.

With regard to cassava, there are several reasons why an integrated control program for diseases and pests is a prerequisite for yield stabilization and satisfactory production. Among these are the following:

1. Cassava is a perennial crop with undetermined physiological maturity (Jennings, 1976); consequently, an established biotic problem could be perpetuated.

2. The vegetative cycle is long, ranging from 8-24 months, depending on the cultivar and/or ecosystem. During this time, the plants can suffer climatic and edaphic pressures (e.g. drought, low or high temperatures, nutritional deficiencies or toxicities), as well as attack by pathogens, insects, mites, and nematodes. The intensity and severity of these stresses vary among ecosystems and from one growing season to another and are related to the ecological conditions occurring throughout each growing cycle and to the existence of material susceptible to the stresses present.

3. Cassava is propagated vegetatively from stakes obtained from lignified stems. The quality of the planting material is determined by the climatic, edaphic, pathological and entomological stresses (negative production factors, NPFs) of the genotypes cultivated in a given cycle and their resistance to these stresses. The quality of the stakes determines, to a great extent, the overal success in achieving optimal yields (CIAT, 1979, 1980; Lozano *et al*, 1977). On the other hand, infected and/or infested propagation material is highly probable in cassava unless preventive measures are taken (Lozano, 1977a).

4. *Manihot esculenta* is composed of cultivated clones that have been selected for desirable characteristics over many years by farmers in each ecosystem, primarily based on tolerance to the NPFs existing in a given region. The introduction of one or several NPFs from other ecosystems and/or planting clones in ecosystems different from the native one can cause serious damage to the original clones, as well as to those planted outside their native ecosystem (Lozano *et al*, 1980).

5.   Several cassava clones are planted in each region throughout the whole or most of the year.  Consequently, in most ecosystems, tissues of diverse genotypes susceptible to different biotic problems are present throughout the year.  The reason for the lack of epiphyotics in traditional plantations or for the presence of biotic problems at levels below the economic threshold is due almost entirely to the biological balance that exists in the ecosystem, and this must be maintained.

6.   Cassava has a long genetic cycle (up to 3 years), which delays the development of new, improved varieties, tolerant to specific problems (Kawano *et al*, 1978), thus a stable-type resistance is preferred.

7.   Cassava growers need to exercise great care in the production of their own planting material to avoid sanitary, agronomic, and economic problems caused by: (a) the low multiplication rate (5-10 stakes/plant) (Lozano *et al*, 1977); (b) damage caused to stakes because they are easily injured during preparation and transportation, as well as the difficulty of subsequent storage (40% of the buds in some clones failed to sprout after only 2 weeks' storage)(Lozano *et al*, 1977); and (c) packing and shipment of stakes, which is difficult and expensive because of their weight and colume (10,000 stakes required to plant 1 ha weight about 1 t and occupy 2 m$^3$).

8.   Most cassava farmers are traditional farmers (Phillips 1974) with little technical knohow and few economic resources. Problems related to this crop shhould be solved using a simple, inexpensive but efficient cultivation system.

Based on the foregoing factors, the importance of integrated crop management in the control of pests and diseases can be seen.  This system must combine good cultural practices with biological control and varietal resistance.

## Cultural Practices

Uniform cultural practices cannot be recommended across all cassava-growing areas; they should be adapted to the specific characteristics of each ecosystem.  Moreover, the incorporation of different practices should be based on a cost-benefit analysis, bearing in ming the farmer's capacity and that stability of production is the ultimate goal.  Some practices may appear unessential, but the roots (the commercial product) may be affected and, unfortunatedly, this can be appreciated only at harvest time.

The following are some cultural practices that, when applied in combination, can reduce or even eliminate stresses

due to NPKs in a given ecosystem, thus producing stable yields.

1. When cassava is planted immediately after the removal of forest, perennial or woody annual crops, severe root-rot problems can appear due to pathogens and/or pests that affect these plant species as well as cassava (Booth, 1977; Bellotti and Schoonhoven, 1978b). A decrease in soil infestation can be obtained by planting nonsusceptible crop species (e.g. cereals) before cultivating cassava and burning the plant debris left on the ground (Booth, 1978; Lozano and Terry, 1977).

2. Soil preparation should be as for any other traditional crop. As cassava is susceptible to flooding and to pathogens favoured by this condition (i.e. *Phytophtora* and *Pythium* spp.), soil drainage must be adequate for the quantity and distribution of rainfall in each ecosystem. For example, planting on ridges is recommended when rainfall is higher than 1200 mm/year. The size and depth of these ridges will vary in relation to soil texture and frequency of rainfall (Booth, 1978; Lozano and Terry, 1977; Oliveros *et al*, 1974).

3. It is well known that the quality of planting material is crucial for the successful cultivation of any vegetatively propagated crop. This is one of the most important factors in any cassava production program, responsible not only for good crop stand and establishment (good rooting of stakes and bud sprouting), but also for the sanitary conditions of the crop and final yield (commercial roots/plant) per unit area per cycle (CIAT, 1978, 1980; Lozano *et al*, 1977).

The quality of the stakes depends on certain agronomic characteristics (lignification, thickness, related to each clone, size, number of nodes/stake, angle of cut, and degree of mechanical damage), sanitary conditions (free of systemic and localized pathogens, insects, and mites), and disinfestant and protectand treatments applied before planting or storage (Lozano *et al*, 1977).

In general, stakes should be taken from the healthiest plantations on the farm or in the region, selecting the most lignified portion of the stem from vigorous 8- to 15-month-old plants, and cutting the stem in pieces 20 cm long at a right angle. Any portion of the stem with signs of necrosis (discolorations), cankers, tumors, galls, galleries, and/or insect (scales, borers, etc) or mite infestations must be eliminated. Infested or infected stakes can contaminate healthy ones during the storage period (Lozano *et al*, 1977; Vargas, 1978).

Stakes must be treated with fungicides and insecticides for disinfection, disinfestation, and protection. Planting material should not be stored unless strictly necessary (CIAT,

1979, 1980; Lozano *et al*, 1977).

4.  Stakes should be planted in accordance with the terrain; satisfactory root formation and distribution result from the position of the stake in the ground (Castro *et al*, 1976). Good root development leads to vigorous plants, which are more resistant to biotic problems and easier to harvest.  This in turn can lead to less physiological and microbial deterioration during storage, which are enhanced by mechanical damage during harvesting (booth, 1976; Lozano *et al*, 1977).

Considerable losses in establishment due to the failure of rooting or bud sprouting can occur if planting is done during the hottest season of the year in areas with high average temperatures.  This may be caused by the effect of soil temperature on horizontally planted stakes; when planted vertically or obliquely, air circulation cools down the extreme upper portion of the stake, reducing the effect of hot soils.  It is necessary to bear in mind that the bud thermal inactivation point of most cultivars is 52.5°C (CIAT, 1974); high temperatures can also damage the stake epidermis, causing openings suitable for the establishment of pests and pathogens.

5.  Good weed control is important because cassava is a poor competitive species (Doll, 1978).  Moreover, adequate weed control could reduce both pathogens and pest populations on other host species and also allow good air circulation between plants, increasing the rate of rainfall evaporation. This reduces the relative humidity for sufficient tiem to decrease the rate of establishment and propagation of some pathogens, insects and mites.  However, certain weeds can serve as a host and food supply for beneficial insects and their elimination would decrease their populations.  Weed control must therefore be carried out with both these aims in mind.  In large plantations, it may be wise to keep plots or bands of native weeds to help maintain a natural biological balance.

6.  Periodic inspections of plantations are highly recommended to: (a) determine the scale and timing of agronomic operations such as drainage weed control, etc.; (b) remove plants or plant parts with initial infection or infestation symptoms of diseases (viruses, mycoplasma, etc.), insects (scales, shoot flies, etc), and mites, which at the initial stages attack scattered plants in the stand.  These plants should be removed from the area in plastic bags and burned to prevent the dissemination of these problems; and (c) forecast the commencement of epiphytotics caused by pathogens and insects, allowing appropriate control strategies to be planned and carried out at the most advantageous time.  A full-time trained worker would be justified on farms of 15 ha or larger to carry out control of agrophytosanitary problems.

579

7.  Because the roots are highly perishable, as a result
of both physiological and microbial deterioration (Lozano *et
al*, 1977) it is suggested that planting and harvesting opera-
tions be programed according to marketing conditions.  Simi-
larly, because the incidence and severity of this deteriora-
tion are enhanced by mechanical damage, this should be mini-
mized or avoided during harvesting, packing, and shipping
(Booth, 1978).

Recent research on fresh-root storage suggests that phy-
siological deterioration is a biochemical process (Lozano *et
al*, 1977; CIAT, 1980) that can be controlled by prunning 2-3
weeks before harvest.  Storage of roots in sealed plastic
bags to prevent dehydration by keeping up the saturated rela-
tive humidity also gives good control.  Microbial deteriora-
tion has been controlled by dipping the fresh roots in a fun-
gicide solution (Lozano *et al*, 1977).

8.  Plant debris left on the ground after harvest can
act as propagation media for pathogens and pests that can
cause severe damage to cassava after successive plantings
(larbae of Coleoptera; *Rosellinia* spp., *Armillariella* spp.,
etc.).  The elimination, especially of stems and roots, can
help maintain these root-rot problems at low levels for sev-
eral planting periods (CIAT, 1979; Lozano, 1978b).

The determination of the percentage of root rot after
each harvest, especially on soils rich in organic matter,
helps determine whether crop rotation or fallowing is advis-
able.

In general, plots that have over 3% root rot at harvest
require crop rotation or fallowing to decrease the inoculum
potential of biotics infesting the soil.  When crop rotation
is planned, care should be taken in the choice of crops in
the sequence, because several other crops are also attacked
by cassava pathogens; cereals are a good choice (Lozano, 1978
b; Lozano and Booth, 1974; Lozano and Terry, 1977).  On the
other hand, cutworm pests of maize and sorghum can also attack
young cassava plants.  It these are present, it is necessary
to apply poison baits or spray the soil with fungal or bacte-
rial pathogens of these insects before planting (Bellotti and
Schoonhoven, 1978b).

9.  Planting time can affect pest and/or disease inci-
dence.  Periods that favour high multiplication rates of pa-
thogens, especially wet periods.in the tropics or coot sea-
sons in semisubtropical areas, should be avoided (Lozano 1978
b; Lozano and Terry, 1977).  By planting over several periods
during several cycles, it is possible to determine the appro-
priate planting time for each ecosystem.

10. Consecutive planting in the same or in different plots over long periods of time can induce a progressive increase in the inoculum potential of pathogens and pests, causing outbreaks of increasing severity with time. A delay in planting for a few months will lead to a decrease in the biotic problem. This can also be reduced by planting stakes of longer than usual length (0.40-0.50 m instead of 0.20 m) to obtain large plants with several buds in a short period of time; these will have a higher tolerance to biotic problems such as shoot flies (*Silba pendula*) than small plants obtained from short stakes.

11. Cultivation of cassava in association with other crops has been reported to be responsible for the low incidence and severity of biotic problems in tropical cropping systems; traditionally managed farms combine this with planting multicolonal cassava plots. This system should be studied and maintained wherever possible, above all where cassava is used as a staple food. Sudden changes in production systems may bring about unexpected changes in the ecological equilibrium, which in the long-term are reflected in the balance existing with the native biological control of the ecosystems.

12. Well-planned spacing of plants can preven the formation of microclimates favourable for the propagation of diseases and pests, as well as decrease the spread of biotic problems within the stand (e.g. scale insects). An ideal spacing can be reached by decreasing plant populations per unit area or changing the planting system (i.e. two rows separated by only 0.5 m, followed by another two at 2 m distance). The effects of such methods should be evaluated according to each ecosystem and its soil fertility, the clone type harvesting systems used, etc.

13. Improvement of growth conditions for cassava by increasing the nutritional level of the soil and the water supply during critical growth periods facilitates vigorous plant development, which in turn produces a higher tolerance to the stresses exerted by the biotic problems within a given ecosystem. However, the use of these cultural practices, their levels, and frequency of application should be determined by economic analysis. In general, plots that are selected for the production of stakes should receive the best cultural and biological treatments.

14. As several biotic problems are disseminated through vegetative and sexual propagation material, it is of great importance to establish and strictly observe quarantine regulations (Lozano, 1977). In general it is suggested that only official institutions be authorized to introduce cassava propagation material; vegetative material should be introduced by meristem culture or sexual seeds taken only from healthy

plantations.

15. The use of sonic light traps, poison baits, pheromo-
nes, gamma and X rays for sterilization, hormones, etc. are
control measures that should be considered to improve the
control of insects during different periods of the crop cycle,
taking into account the biotic problem, the ecosystem, and
the feasibility of its execution (Bellotti and Schoonhoven,
1977, 1978b; Bellotti *et al*, 1980).

## Biological Control

The long production cycle of cassava makes chemical con-
trol of pests uneconomical. This fact, combined with the
great ability of the cassava plant to recover from abiotic
and biotic stresses, indicates that biological control may
prove very effective (Bellotti and Schoonhoven, 1978b; Bello-
tti *et al*, 1980). Moreover, many beneficial agents exist in
cassava plantations; in the case of *Erinnyis ello* alone, some
30 parasites, predators, and pathogens have been identified
(Bellotti *et al*, 1980). Biological control should constitute
one of the most important approaches of any integrated control
package for the diseases and pests of all ecosystems.

The following suggestions can help maintain the natural
biological control already present in a given ecosystem and
improve it by increasing populations of native or introduced
beneficial agents.

1. Although pesticides are valuable components of inte-
grated control, they must be used only when other control mea-
sures are not effective and when it is economically necessary
because of yield reductions caused by the biotic problem (Be-
llotti *et al*, 1980; Lozano 1978a). If an outbreak requires
pesticide applications, this shoudl be selective with, it pos-
sible, a low lethal effect on beneficial agents (Bellotti and
Schoonhoven 1978a; Bellotti *et al*, 1980).

2. A detailed inventory of beneficial insects and micro-
organisms as well as of pests, diseases, hosts and food-sour-
ces of these pests is urgently required. The evaluation of
each biotic problem in each ecosystem will aid in the esta-
blishment of priorities for each approach to biological con-
trol.

3. Ecological studies directed toward explaining the re-
lationship between parasites, pests, and the environment will
provide valuable information for future strategies on biolo-
gical control for each ecosystem.

4. Natural biological control can be improved by increasing the populations of the most beneficial species through mass rearing, followed by liberation and colonization (Bellotti *et al*, 1980). It can also be improved by the introduction of new, more efficient beneficial species or biotypes that can be adapted to the conditions of a particular ecosystem.

5. Even though modern agriculture uses the monoculture /homogeneous genotype system for several crop species, our experiences with cassava lead us to suggest that it would be better to use the multivarietal system in monoculture or mixed cropping with other crop species, as is the current practice among most cassava growers. The genetic clonal variability in plantations restricts the asemic propagation of pests and pathogens, keeping their populations at low levels, greatly reducing the risk of sudden outbreaks.

6. Alternate hosts of pathogens and pests, grown in or near cassava plantations (e.g. *Poinsettia pulcherrima*, host of the causal agent of superelongation disease), should be removed, as well as any source of food for pathogens and pests (the hornworm eats leaves for rubber trees; fruitflies feed on rotting fruits; several soil-borne pathogens live on decaying cassava root debris, etc.). Extension programs should explain the advantages of carrying out these practices and if host cannot be eliminated because of their economic importance (rubber trees in Malaysia and Brazil, for example), integrated control programs should also be planned for these crop species.

7. The liberation of erradicated insects or interspecicic hybrids of pests in the area has not yet done been done in cassava, but would be a promising biological control system for the future. Spraying the soil with bacteria, fungi, viruses, etc. that are pathogenic to soil-borne insects and pathogens of cassava, is another good possibility that merits study.

## Varietal Resistance

Yield stability with time in a given ecosystem is related to the stresses resulting from the NPFs existing in each ecosystem, as well as to the genetic capacity of clones to tolerate these stresses. Because cassava clones have been selected for a very long time in localized areas and perpetuated vegetatively, the cassava/ecosystem interaction is great. A good, well-adapted clone with tolerance to a given ecosystem could be severely affected by the NPFs of another ecosystem. Consequently, in each particular ecosystem, regional clones or clones form similar ecosystems should be preferred to those introduced from ecosystems with different sets of NPFs. Intro-

ductions should be made specifically to improve the gene pool existing in each ecosystem (regional clones). Improvement programs should be decentralized and located in areas selected on the basis of extensive agro-socioeconomic studies (Lozano *et al*, 1980).

The concept of varietal evaluations should be multiple, integrating the following three general concepts: (1) a satisfactory yield of fresh roots, starch, foliage, etc. according to its utilization; (2) a good production of high-quality planting material; and (3) a highly acceptable root quality according to the socioeconomic requirements in each region. Clones selected according to these criteria would probably be the most stable over time, being the most acceptable to farmers.

Clonal evaluation in each ecosystem should be directed to identifying genotypes with the widest type of resistance to the NPFs existing in it; this evaluation should be performed by observations in areas where the NPFs of each ecosystem are most severe and most frequent. These evaluations should be integrated, performed by scientists of different disciplines and during several consecutive cycles (CIAT, 1978; Lozano *et al*, 1980). This should not eliminate or underrate evaluations directed to identifying tolerance to specific important biotic problems because this could be needed to improve clones having wide-type resistance but susceptible or deficient in certain required characteristics.

Varietal resistance obviously improves biological control of the area because economic damage occur only at higher population levels, facilitating the increase of beneficial biotics and reducing or eliminating the need for pesticides. In cassava an attack of *Erinnyis* spp. can produce up to 40% defoliation without causing any yield loss; this permits a delayed insecticide application for their control or the use of any other control measure compatible with the biological equilibrium of the region.

The foregoing general recommendations for the integrated control of diseases and pests in cassava should be complemented by scientific support given by research and extension agencies to growers and processors. The long-term success of cassava production in a given country or region may depend on both the research support and the appropriate application of these control measures.

# PRODUCTION OF CASSAVA PLANTING MATERIAL

Quality cassava "seed" production depends on several factors, including the type of material used, sanitary conditions and storage. The quality of the seed per se is determined by the age of the stem used, the number of nodes per cutting, the thickness of the cutting, varietal differences in germination, and the extent of mechanical damage that the cutting may suffer when it is being prepared, transported and planted.

Seed quality can be reduced by the presence of systemic, localized or soil-borne pathogens, as well as by the attack of mites and insects that may be found on the surface of the stem cutting, within the stem, and/or in the soil.

Storage generally reduces germination of cuttings as a result of dehydration or attack by pathogens and other pests during the storage period.

To avoid problems involved with cassava planting material, cuttings should be selected carefully from good-quality stems; they should be disease and pest free and treated with eradicant as well as protectant fungicides, insecticides and/or acaricides. This treatment makes it possible to store cuttings for periods of more than 30 days.

Cassava (*Manihot esculenta* Crantz) is a perennial shrub that is best propagated vegetatively. The swollen roots accumulate carbohydrates. Since the plant does not mature physiologically, the roots are harvested from 7 to 24 months of age, depending on the ecological conditions, on the demand for the product, and on the variety used. It should thus be considered as a crop with a long growing cycle.

In any vegetatively propagated crop, good cuttings are necessary for high yields; in cassava, losses in germination may reduce yields drastically. Unfortunately, this aspect is underestimated by the majority of farmers. In most cassava plantations, the plant stand is lower than the number of cuttings planted originally; there is little uniformity in plant vigor from one plant to another; production per plant varies considerably; and root rots are generally found at harvesting. Although edaphic and climatic factors may account for some losses, the use of high-quality, clean cuttings will generally reduce the relative frecuency and intensity of losses.

In addition, systemic pathogens (viruses or viruslike organisms, mycoplasmas, bacteria and fungi), as well as mites and insects that attack the cassava stem, are disseminated through the use of infected propagating material, and are thus

frequently introduced into plantations, regions, countries or continents where they did not previously exist.

For these reasons it is of utmost importance that cassava growers always use good-quality seed in order to obtain uniformity in their establishment, as well as good production, to reduce root rots, and to prevent the introduction of pests not found in the area. Good cassava seed is produced from clean, quality stems; proper storage is also important.

Quality of the Cassava Seed

The quality of cassava seed depends on stem age, thickness, number of nodes per cutting, and size. Although there have been no conclusive findings in this respect, repeated observations indicate that control of these factors is essential for the germination of vigorous plants capable of producing a good number of commercial roots.

Age of the Stem

The most suitable age of the stem cutting has not been determined. Nevertheless, it is well known that although cuttings from green stems (slightly lignified) will germinate, they are extremely susceptible to attack by soilborne pathogens as well as by sucking insects. Besides, immature herbaceous (green) stem cuttings cannot be stored for a long period of time since they have a high water content and tend to dehydrate rapidly. Also, since they are succulent, many microorganisms (bacteria and fungi) attack them, causing severe rot a short time after planting.

When cuttings are taken from plants more than 18 months old, the stem is highly lignified, containing only a small amount of food reserves for the shoots that germinate from the buds. For this reason, germinating buds have reduced viability, present delayed germination, and/or produce shoots of little vigor. These older stems may also have suffered a greater number of lesions caused by localized pathogens or insects. It is also more difficult to prepare the cuttings from older, woody stems.

It is recommended that planting material be taken from plants ranging from 8 to 18 months of age. The younger the plant, the more lignified should be the part of the stem selected for the cutting. One practical way of knowing whether a stem is sufficiently mature is to determine the relationship between the diameter of the pith and the stem cutting in a transversal cut. If the diameter of the pith is equal to or less than 50 percent of the diameter of the stem, it is sufficiently mature to be used for planting.

## Number of Nodes per Cutting

Each stem node has an axilliary bud; theoretically, one
plant can be obtained from each node. Nevertheless, it has
been found that cuttings with one to three nodes have low per-
centage of germination under field conditions since they are
very short and therefore more susceptible to rapid dehydration.
Also, pathogens can invade the whole cutting in a relatively
short time. Finally, cuttings with few buds have a greater pro-
bability of losing the viality of all their buds during their
preparation, transportation and planting. Long cuttings with
more than ten nodes theoretically have a better chance of con-
serving their viability because of the greater number of buds.
Nevertheless, when long cuttings are used, much more propagat-
ing material per unit of surface area is required, and there
is also greater possibility that this material will be affect-
ed bu localized pathogens and insects.

Based on these data, the stem cuttings used should have
from 5 to 7 nodes and a minimum length of 20 cm.

## Thickness of Cuttings

Although any part of the cassava stem can be used for pro-
pagating material in a commercial operation, thin stems, which
have fewer nutrient reserves, should not be used since shoots
are weak and only a few small swollen roots are produced. As
a general rule, it is recommended that the thickness of the
stems used for cuttings should not be less than one half the
diameter of the thickest part of the stem of the particular
variety being used.

## Variety

Great varietal differences exist as regards the germinat-
ing capacity of cuttings. These differences are accentuated
when the cuttings are stored: the longer the period of storage,
the greater the differences (Sanay and Lozano, personal infor-
mation). Therefore, varieties with a higher germinating capa-
city should be used. The germinating capacity of any given
variety can be determined easily by evaluating the percentage
of germination among cuttings from different varieties after
a short shortage period; e.i. 15 days.

## Mechanical Damage

The epidermis and buds of cuttings can be bruised or damaged by friction and machete wounds during their preparation, transportation, storage and planting. Each wound is a new site of entry for microorganisms that cause rot during storage or after planting. It is very important that all precautions be taken to avoid rough handling when cutting and transporting the stems or branches that have been selected for propagating material. the cut should be made with a well-sharpened machete or circular saw, in which case the stem should be held with both hands while it is being cut. When the cut is made at a right angle, perimetral and uniform rooting is obtained.

## Sanitary Condition of the Seed

The stem of the cassava plant is attacked by various pathogens that induce internal or external rot and/or cortical or epidermal cankers. Other pathogens invade the woody stem tissue systematically without leaving any visible symptoms (viruses, mycoplasmas, cassava bacterial blight). The cassava stem is also attacked by insects and mites that are localized on the epidermis or within the stem.

## Pathogenic Aspects Related to Cassava Seed

Based on their localization and presence on the stem, the pathogens attacking cassava can be grouped as follows:

1. Systemic Pathogens. are vascular [viruses and mycoplasmas; *Xanthomonas manihotis*] and cortical or epidermal [*Sphaeloma manihoticola*] causal agents that invade teh host systematically without leaving any visible signs in the mature portion of the stem. For this reason a high percentage of the plants coming from diseased cuttings are diseased; these plants may constitute the source of primary inoculum in the new plantation. It is by this means that systemic pathogens are disseminated from different regions, countries and/or continents.

To prevent the presence of these pathogens, it is essential to use healthy seed. For example, African mosaic, which appears to be caused by a polyhedral virus, is not found in the Americas or Asia (except for India); however, its vector (the whitefly *Bemisia* spp.) has been reported in Latin America. For this reason it is vital to prevent the introduction of propagating material from Africa and India. In places where the disease is found, its incidence has been lowered through the selection of

apparently healthy plants for diseased fields. Resistant var-
ieties exist, but their seed may bear the causal agent, thus
constituting the source of inoculum for plantations where sus-
ceptible varieties are used.

It was recently shown that apparently healthy plants can
be produced by culturing plant meristem taken from plants in-
fected with African mosaic. Nevertheless, since there is still
no method that detects the presence of the causal agent in the
host, the system does not provide a margin of absolute safety.

The American viruses (common mosaic and leaf vein mosaic)
and mycoplasmas (witches'-broom) appear to be transmitted in
cassava only by mechanical means and in relatively low percent-
ages. Threfore, the percentage of infection from these diseases
is limited. Since disease-free plants are always available for
selecting seed for planting, disease can be eradicated with a
high degree of efficiency by roguing plants with disease symp-
toms. If this does not completely eradicate the disease, it
will at least reduce the percentage of potential inoculum to
a greate extent.

It has been shown that healthy plants can be obtained from
plants affected with cassava bacterial blight by tacking shoots
(5 to 10 cm) from cuttings from diseased plants, using the me-
thod of rooting in sterilized water. The plant obtained by
this method constitute the foundation for production certified
disease-free seed. The foundation stock can be multiplied by
traditional methods of by using the rapid propagation method
developed by Cock *et al*. The disease-free material can then be
used to plant lots where cassava has not been planted before or
where the pathogen has been eradicated by a six-month rotation
with other crops or crop fallowing. This seed can be distribu-
ted without risk to other regions where the disease does not
exist.

The causal agent of superelongation (*S. manihoticola*) can
also be introduced by using cuttings taken from infected plan-
tations. For this reason, only cuttings from healthy, disease
free plantations should be used. It has been found that treat-
ing cuttings with fungicides such as Difolatan and Orthocide
(4000 ppm ai.), the pathogen can be eliminated from the cuttings.
One of these fungicides should therefore be used to treat the
cuttings that are taken from areas where the disease is endemic.

2. Localized Pathogens.- are nonsystemic pathogens (cau-
sal agents of bacterial stem rot, anhracnose, concentric-ring
leaf spot, some basidiomycetes, etc), that invade only a part
of the stem. These pathogens generally leave cankers of light
brown to black necrotic areas on the epidermis of the stem.
Other pathogens such as the causal agent of bacterial stem rot
also invade the pith region, which turns reddish yellow to dark

brown in color.

This group of pathogens enters the stem through wounds produced mechanically or by insects, or by invading the leaf petioles, penetrating them directly or through the stomata. Others enter directly into the stem, rapidly invading the green portion. The degree of invasion decreases as the stem becomes lignified.

Any part of the stem that is healthy and that does not show any signs of attack from localized pathogens can be used for planting material. When selecting seed, all parts that are affected by these pathogens-i.e., cankers, blackish epidermal areas or reddish pith areas-should be destroyed. It is also advisable to disinfest machetes or saws taht are used to cut stems, cleaning them with commercial preparations of formaldehyde at 5 percent to prevent mechanical transmission of the disease through infested tools.

3. Soil-borne Pathogens.- that commonly attack some other hosts such as forest trees (*Fomes lignosus, Rosellinia necatrix, Armillariella mellea*), perennial crops such as coffee, bananas and plantains (*Fusarium* spp., *Rosellinia* spp., etc.), and herbaceous crops with short growing cycles such as cotton and beans [*Rhizoctonia* spp., *Sclerotium rolfsii, Whetzelinia (Sclerotinia) sclerotiorum, Phytophthora* spp., *Pythium* spp.] often attack cassava as well. Attack by these pathogens occurs once the cuttings have been planted, beginning at the ends of the cutting, entering through the epidermal wounds or at the base of the shoots and/or in the rootlets.

The best way to prevent cuttings and seedlings from attack by these pathogens is to diminish soil infestation by rotating cassava with non-susceptible crops such as Gramineae and by using certain cultural practices such as good drainage and planting on ridges. In addition, it has been shown that treating the cuttings with disinfestants, disinfectants and seed protectants is highly advantageous. Treating cuttings with certain fungicides or mixtures of these has the following advantages: (1) a disinfestant effect, (2) protectant action, (3) longer storage time, and (4) accelerated germination, rooting and growth. Among the fungicides and mixtures that can be recommended are Orthocide + Bavistin, Daconil + Manzate, Dithane M-45 + Manzate, Demosan 65, Brassicol 75, Vitigran and Agallol (2000 ppm a.i. in mixtures; 4000 ppm a.i. when used alone). Miztures usually provide a broader protective spectrum.

The cost of the treatment is relatively low (see Table) since only one preparation is required for treating a large number of cuttings. Therefore, it is recommended that this treatment be done as a matter of routine immediately after

590

the propagating material has been prepared. Results suggest that once cuttings have been treated, yields will increase more than 25 percent and the material can be stored for one month without losing its germinating capacity (Sanay and Lozano, personal information). If superelongation is found in the region, Difolatan or Orthocide should be used. In addition, as discussed below, an insecticide such as malathion, Tamaron or Basudin should be used to control insects found on the surface of the cutting.

## Entomological Aspects of the Cassava Seed

There are mites and insects that attack the cassava stem, reducing the production and the quality of the propagating material that comes from affected plants.

There are also soil-borne insects that attack cuttings after they are planted, causing wounds or boring holes through which soil-borne pathogens can enter. They may also destroy the epidermis and/or buds of the cuttings completely. Other insects cut the roots and/or shoots shortly after their emergence. Mites and insects attacking cassava can be classified as follows:

1. **Mites and Insects on the Stem Surface.-** Mites generally attack leaves and green parts of the plant. When they migrate, they are found on the stem surface of the infested plants, where they attack the germinating buds. Through infested material, they can be carried to other geographical areas and continents. For example, *Mononychellus tanajoa* was introduced to Africa on infested cuttings. The scale insects (*Aonidomytilus albus, Saissetia miranda,* etc.) and the mealybug (*Phenacoccus gossypii*) are also disseminated in this manner. These insects can reduce the germination of infested cuttings up to 70 percent, depending upon the degree of infestation. The eggs and larvae of other insects such as thrips (*Frankliniella williamsi, Corynothrips stenopterus, Caliothrips masculinus*), mealybugs (*P. gossypii*), lace bugs (*Vatiga* spp.) and others can also adhere to the surface of stems and are spread when the infested cuttings are transported from one place to another.

In order to prevent mite and insect infestations on cuttings, acaricides and insecticides such as malathion E.C. (100-300 ppm), Tamaron (200 ppm) or Basudin (200 ppm) should be used. These products can be applied by dippling the cuttings in the solution for 5 minutes; they can also be mixed with the fungicides that are recommended as protectants, disinfestants and /or disinfectants (see Table).

2. **Insects Found Within the Stem.-** The insects that are found in the cassava stem are generally stemborers (various

591

species of Coleoptera, Lepidoptera and Hymenoptera). Larvae of these and other insects such as the fruit fly (*Anastrepha* spp.) and the surface or subterranean cutworms that feed on the stem (*Agrotis ipsilon*, *Prodenia eridania*) are often carried inadvertenly from one place to another. The tunnels and galleries they make in the stem are another means of access for microorganisms that cause stem rot.

To avoid using cuttings that have wound or that are infested with insects, a careful selection should be made of the stems beforehand. Any part of the stem that has external or internal lesions caused by insects should be discarded and burned. Internal damage can often be noted by discoloration of the pith.

3. Soil-borne Insects.- Some insects that attack cassava cuttings after planting are found in the soil. They usually destroy the cortex of the cutting and make tunnels, which favor microbial rots. Losses in germination and/or sudden death of the seedlings result. The most common soil insects are white grubs (Coleoptera belonging to the families Scarabaeidae or Cerambycidae), termites (*Coptotermes* spp.) and cutworms (*Agrotis* spp.). To prevent the attack of these insects, aldrin should be incorporated in the soil (1.5 kg a.i./ha) or carbofuran (0.9 g a.i./plant) should be placed immediately under the cutting. In the case of termites, a residual insecticide such as aldrin, dieldrin or chlordane should be used. Toxic baits (i.e., 10 kg sawdust, 8 to 10 liters water, 500 g sugar or molasses, and 100 g trichlorphon for 1/2 to 1 ha) also give excellent results.


Storage of Cuttings

Farmers usually store cuttings while they prepare the land for planting or until the rainy season begins. While the cuttings are being stored-whether already cut or in long pieces of stem- buds usually germinate, pathogens and insects contaminate the material, and the material dehydrates. Longer storage periods generally lead to more severe damage. The material may dry out, with signs of visible rotting and cankers on the cortex; or immediately after the cuttings are made, they may lose their germinating capacity. The final result of storage is a reduction in plant population per unit of surface area, which becomes more severe as the period of storage increases.

It has been found that more than 90 percent germination can be obtained after one month of storage when 20- to 50-cm cuttings or stem pieces are treated before storage with the protectant fungicides recommended previously (see section on soil pathogens).

An additional treatment before planting (with the same fungicides) favors germination even more. These treatments can be made when applying the insecticide for controlling the isects found on the cuttings. To prevent dehydration of the cuttings during storage, long pieces of stem, preferabley 50 to 80 cm, should be used. When preparing the cuttings, the 10 cm at each end of the stored stem should be discarded.

The storage area should be well shaded and offer high, but not excessive relative humidity (about 80%) and moderate temperatures (20-30°C). Planting should be done when there is adequate soil moisture since high soil temperatures inhibit germination and the thermal inactivation point of cuttings is low.

Although it is not known whether there is varietal resistance to the factors that damage cuttings during storage (dehydration, attack by pests, and rapid germination of the buds), highly significant varietal differences have been found (Sanay and Lozano, personal information). Consequently, varieties that have a high germinating capacity should be used.

## Conclusions

It is necessary to plant good cassava seed in order to obtain high yields. In order to obtain good seed, the following points should be considered:

1. Good-quality seed comes from a variety with good germinating capacity. The part of the stem selected for the cutting should be of sufficient maturity (between 6 and 18 months old), have 5 to 7 nodes, measure at least 20 cm in length, and have a diameter of more than one half the maximum thickness of the stem of the variety planted.

2. Care should be taken to prevent mechanical damage to the cuttings during their preparation, transportation and planting. The cuts should be even and transverse.

3. Propagating material should not be introduced from Africa mosaic infected regions to clean areas.

4. Propagating material should not be introduced from regions where there is cassava bacterial blight or superelongation. When these diseases are present in a region, sources of planting material should be taken only from those plantations that remain disease free during the rainy season. If there is no such material available, material free of bacterial blight should be produced and the cuttings treated with fungicides that will eradicate the causal agent of superelongation (Difolatan and Orthocide).

5. Cuttings should not be taken from plants that present symptoms of virosis or mycoplasmosis. All such plants should be rogued and burned.

6. All cuttings should be checked carefully a.d. any piece of stem that shows signs of localized pathogens (localized epidermal cankers or pith rotting) and insect damage (galleries or tunnels, epidermal wounds) should be destroyed.

7. Cuttings should be treated with fungicides and insecticides as soon as they are cut from the plant and before storage. Storage should be reduced to a minimum, preferably no longer than 30 days.

8. Cuttings should not be planted in soil infested with insects (white grubs, termites, cutworms) without applying insecticides around the cuttings or in the soil.

9. Planting should be done when the soil has a good moisture level and not during the dry season. Good agricultural practices should be used, preparing the soil well before planting.

10. If upon harvesting, there is a lack of uniformity in production and more than 5 percent root rot, cassava should be rotated with Gramineae for a period of no less than six months.

# CASSAVA QUARANTINE

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## INTRODUCTION

Cassava (*Manihot esculenta* Crantz) is grown throughout the tropical regions of the world. Its starchy roots are a major energy source for over 400 million people. A member of the Euphorbiaceae, cassava was domesticated in the Americas more than 5000 years ago.

The cassava plant is a perennial shrub whose leaves are formed at active apices and consist of an elongated petiole and a palmatic leaf blade. The plant exhibits apical dominance, producing a single stem with petioles borne on raised structures, giving the stem a characteristic knobby appearance. When the main apex enters the reproductive stage, apical dominance is broken; and two or four axillary buds immediately below the reproductive structure develop and branching occurs. Carbohydrates accumulate in the root parenchyma to form swollen storage organs. The growing season ranges from 8 to 24 months depending on ecological conditions. The cassava plant can be grown from seed but is usually propagated vegetatively from stem cuttings. Cassava is grown commercially at altitudes between sea level and 2000 meters.

During the last decade the importance of increasing cassava production and research has been realized because of the shortage of carbohydrates in tropical regions. Many tropical countries lack foreign exchange to import sufficient carbohydrate sources, and too often population growth in cassava-producing countries is above the world average. Cassava is regarded as one of the best crops for carbohydrate production even on the very poor soils typical of many tropical countries. Consequently, the exchange of cassava propagating material as botanical seed, stem cuttings or meristem-cultured plantlets has

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increased considerably with the aim of improving cassava pro-
duction. Such exchange may be between continents (i.e., the
Americas with Asia, Australia and Africa), between countries,
or between regions in the same country (i.e., the transitional
areas between Campo Cerrado and the Amazonas regions of Brazil).
The risk of introducing pests and pathogens into new areas is
very high and unfortunately has already taken place, resulting
in severe crop losses and famine in some regions.

DISEASE AND PEST COMPLEXES

Approximately 60 fungi, 5 bacteria and 4 viruses have been
reported as cassava pathogens. In addition, several mycoplasma
and viruslike diseases occur in the Americas. Most cassava pa-
thogens appear to have evolved with the host in the Americas,
with the apparent exceptions of African cassava mosaic virus
(ACMV), which occurs in Africa and the Indian subcontinent, and
cassava brown streak virus (CBSV), reported from east Africa.
Fortunately, most disease agents are still confined to their
purported centers of origin as a result of isolated cropping
systems in each region and the limited movement of germplasm
from the Americas. Nevertheless, there have been several recent
introductions of pathogens into new areas within the Americas
and from the Americas to other continents.

Over 200 species of insects and mites have been reported
as cassava pests but the majority are of minor economic impor-
tance. Spider mites, thrips, stemborers, whiteflies, mealybugs,
scales and hornworms represent the most important cassava pests.
All of the 17 most important pests are found in the Americas;
12 of these are also present in Africa and 5 can be found in
Asia. The green spider mite (*Mononychellus tanajoa*) and the
mealybug (*Phenacoccus manihoti*) both originated in the Americas
but now cause devastating yield losses in Africa. The white
scale (*Aonidomytilus albus*), possibly of American origin, is
now found worldwide. *Bemisia tabaci*, the whitefly vector of
ACMV, is found throughout Africa and Asia but is not a serious
pest of cassava in the Americas.

QUARANTINE PROBLEMS

The exchange of cassava stem cuttings is probably the major
means of disseminating cassava pathogens and pests. The intro-
duction of green spider mites, mealybugs and the bacterial
blight pathogen into Africa are important examples of this.
The bacterial blight pathogen (*Xanthomonas campestris* pv. *mani-
hotis*) can survive in the xylem vessels of infested stems for
months. Cassava viruses and mycoplasmas are efficiently harbor-

ed in stem cuttings from infected plants and readily trans-
ferred to plants propagated from infested cuttings. *Mononyche-*
*llus tanajoa*, *P. manihotis* and *A. albus* can survive for months
by feeding on the lateral buds of stem cuttings.

The green spider mite was introduced from the Americas
(probably Brazil) into Africa before 1960. It was first report-
ed in Uganda in 1971 and then spread rapidly to over 60% of the
cassava-growing areas of Africa. This pest is now found in a
wide belt from Mozambique northward through Zaire and the Cen-
tral Africa Republic to the coastal regions of west Africa in
Senegal and Guinea Bissau.

Green spider mites reproduce rapidly in a hot, dry climate.
Development is completed in 8 to 12 days, and each female mite
produces an average of about 50 eggs in a two- to three-week pe-
riod.. The larvae, both nymphal stages and the adults feed on
young leaves, causing severe chlorosis and up to 95% leaf area
reduction during the dry season when population levels are very
high. In severe infestations the entire apical shoot dries up
and dies. As the food supply on infested plants is depleted,
the females drop silken threads 15 to 30 cm long and can drift
in the wind for long distances. This mechanism account for the
rapid spread of the green spider mite in Africa of up to 375 Km
per year.

The cassava mealybug was probably introduced into Africa
around 1970, but may have been present earlier. Spread has
been rapid because of favourable environmental conditions and
the lack of natural predators. Severe attacks of cassava mealy-
bugs can cause almost complete leaf loss and up to 80% reductions
in root yield. The reduction in leaf canopy allows weeds to
develop, causing further crop loss by competition. Although
the plant may recover with the onset of the rainy season, the
resulting weakened planting material will produce a more sus-
ceptible plant the following season.

The cassava mealybug is a parthenogenetic species, develop-
ing from egg to adult in 27 days under tropical conditions.
The adults live about 20 days, during which time they produce
as many as 400 eggs, most of them in the first 10-day period.
The mealybug attacks the growing points of the plant first, pro-
ducing a stunted, bunched effect in the terminal shoots. A to-
xin present in the salivary juice contributes to this leaf dis-
tortion. Very young plants may be killed, and any attacked
plant is significantly weakened.

It has been estimated that these two pests cause economic
losses of nearly 2 billion dollars per year in Africa. In some
areas, losses are so severe that farmers are beginning to aban-
don the crop altogether despite its long history as a famine
food.

Cassava bacterial blight (CBB), caused by (*X. campestris* pv. *manihotis* was introduced into Africa via infected cassava cuttings, possibly in the early 1960s. In 1973 it was first recognized as a significant disease on the African continent in Nigeria and later in Zaire. In 1975-76 the disease was found in other African and Asian countries.

Bacterial blight has been considered one of the most important diseases of cassava in Africa and in many regions of America. Losses of 100% have been reported on susceptible clones growing in environmental conditions that favor the disease. Although it has been reported in almost all cassava-growing countries, there are still many areas within these countries that remain free of the disease; nevertheless, CBB remains a threat unless its introduction is prevented.

It is suspected that cassava viruses have also spread into new cassava-growing regions via the interchange of infected vegetative material. It has not been possible to substantiate claims of introduction because, with the exception of ACMV and cassava common mosaic virus (CCMV) cassava viruses and viruslike agents have not been sufficiently characterized.

Pathogens and Pests Disseminated Via Botanical Seed

Several cassava pathogens can be disseminated by the interchange of botanical seeds. They can be divided into two broad groups: (1) those that infest the seed and (2) those that infect it.

Information regarding the dissemination of pathogens via infested seed does not currently exists in the literature, but the possibility cannot be overlooked. Cassava seeds are produced in a tricapsular fruit, and infestation may occur after fruit dehiscence when the seeds are released. If the seeds fall to the ground, the probability of seed infestation is higher than when the seeds are collected and stored under controlled conditions. Pathogens of cassava that can probably infest the seeds and survive on them are those producing abundant muscilagenous propagules, such as *Colletotrichum* spp., *Phoma* spp., *Diplodia* spp., and *X. campestris* pv. *manihotis*. In many cases the infestation of the storage containers could be much riskier than of the seed per se.

Pathogens that infect cassava seeds include *X. campestris* pv. *manihotis*, *Diplodia manihotis*, *Fusarium* spp. and *Cladosporium* spp. However, considering the limited information available at present, this does not preclude the possibility of other fungal and bacterial pathogens.

A high percentage of botanical seeds collected from CBB-

598

affected plantations are symptomless carriers of *X. campestris* pv. *manihotis*. Similarly, seeds collected from many apparently healthy plantations are also affected by fungal pathogens ad saprophytes. When infections by CBB or fungal pathogens are severe, the seed show deformations, necrotic areas on the cotyledons and endosperm, and corrugation of the testa. These seeds have a very low germination rate. In CBB-infected seed without visible symptoms, the bacterial pathogen is generally located in the embryo in a dormant state, which is overcome soon after germination. The seeds germinate normally, but disease symptoms are visible along the stem or leaves.

Information on seed transmission of cassava viruses and viruslike agents is incomplete. Neither ACMV or CCMV is transmitted via cassava seeds; however, determination of the seed transmissibility of all cassava viruses is essential for the safe interchange of botanical seeds. This task will be facilitated by the eventual characterization and development of sensitive indexing methods for each of the cassava viruses.

In relation to insects, there are few insects that attack cassava seeds so the risk of disseminating these pests is relatively low. Adult female fruitflies (*Anastrepha manihoti* and *A. pickeli*) oviposit on fruits, and larvae feed on immature seeds, consuming them completely. The risk of dissemination is minimal as intact fruits are generally not distributed. This may be one of the reasons why cassava fruitflies are still confined to the Americas.

## Pathogens and Pests Disseminated Through Vegetative Planting Material

The dissemination of cassava pathogens and pests through vegetative material is much more probable than through botanical seeds. During the long vegetative cycle of the cassava plant, the stem which is normally used for propagation, is exposed to infestation and infection by fungal, bacterial, mycoplasmal and viral pathogens, as well as by insects and mites. Lignified stems can also be invaded by most cassava pathogens without showing visible or easily noticeable symptoms.

### Pathogens

Considering the type of invasion and damage caused, cassava pathogens can be classified as localized or systemic:

#### Localized Pathogens

These pathogens are unable to invade the plant systematic-

599

ally; thus damage is localized to limited areas or portions of the plant. Characteristic symptoms are usually the formation of cankers, galls, necrosis of the epidermal or cortical areas (yellow to blackish brown coloration), and deterioration of the pith. Pith, cortical or epidermal degradations can be specific to a given causal agent or to a complex induced by several pathogens.

The most common symptoms caused by localized pathogens are galls (*Agrobacterium tumefasciens*); cankers(*Elsinoë brasiliensis*); epidermal and cortical ulcers (*Colletotrichum* and *Phoma* spp.); vascular streaking (*Diplodia manihotis*, *X. campestris* pv. *manihotis*, *Verticillium* spp.); pith and cortical degradation (*E. carotovora* pv. *carotovora*); and bud necrosis (*X. campestris* pvs. *manihotis* and *cassavae*).


### Systemic Pathogens

These pathogens are able to invade susceptible plants systemically. Generally, a systemic invasion does not produce visible symptoms on the lignified mature stem portions, making it almost impossible to identify diseased material. Symptoms are usually noticeable on leaves, very young unlignified branches, or on the roots. Furthermore, it has recently been found that there are some systemic pathogens, such as viruses, which do not produce visible symptoms on all clones while still causing a significant reduction in vigor and yield. From the standpoint of quarantine, these types of pathogens are very important and merit special attention. The following systemic pathogens can be disseminated by the use of infected vegetative material.


1. **Fungal Pathogens.**- *Diplodia manihotis* and *Fusarium* spp. are the most important fungal pathogens affecting cassava production. These fungi induce vascular streaking along the stem, which results in wilting. In the case of *D. manihotis*, epidermal symptoms are only noticeable on the very young portion of the stem, which makes it very difficult to detect diseased vegetative material. A similar syndrome is also noticeable in the case of infections induced by species of *Verticillium* and *Fusarium*. Although *E. brasiliensis*, the causal agent of superelongation disease, is not a systemic pathogen, it primarily infects the stem epidermal tissues, causing minute cankers that are difficult to identify visually.

2. **Bacterial Pathogens.**- *Xanthomonas campestris* pv.*manihotis*, the causal agent of CBB, is one of the most important pathogens of cassava. The distribution of infected vegetative planting material from diseased plantations has been the main means of disseminating this pathogen over long distances into Africa, Asia, and other regions where it did not exist before.

This is due mainly to the lack of visible symptoms on lignified stems and the pathogen's ability to survive in the invaded tissues for a very long time. However, the report that *X. campestris* pv. *cassavae* can be disseminated through the use of infected cuttings because of its systemic invasion needs further confirmation.

3. Mycoplasmal pathogens.- Mycoplasmalike organisms (MLOs) have been associated with several cassava diseases in Brazil and Colombia. The MLOs described from Brazil induce severe witches' brooming, yellowing, vein clearing and stunting. The MLO from Colombia affects the floral parts, causing an antholysis syndrome, a progression of virescence, hypertrophy and phyllody. The insect vectors involved in the transmission of the cassava MLOs are not known, but all are disseminated efficiently via cuttings from infected plants. The incidence and distribution of the cassava mycoplasmal diseases is low, but the root yield of infected plants can be reduced substantially even when only the floral parts are affected. MLOs have been successfully eradicated from cassava cuttings by thermotherapy in a hot water bath and from infected plants by chemotherapy with tetracycline and streptomycin. It is possible to detect MLOs in the sievetubes of infected plants with the aid of an electron microscope.

4. Viral pathogens.- All viruses and viruslike agents of cassava can be disseminated via vegetative material from infected mother plants. The identification of virus-free plants based solely on freedom from typical symptoms is unreliable under field conditions because the expression of disease symptoms can be suppressed by environmental conditions, particularly temperature, and confounded by pest and pathogen damage or symptoms due to nutritional disorders. If possible, cassava plants should be assessed for freedom from virus symptoms only under optimal conditions for symtom expression. Nevertheless, several viruslike agents found in Latin America remain symptomless in most cassava clones and can only be detected by grafting to a susceptible, symptom-producing clone. Although apparently virus free, the yield and vigor of infected plants are significantly reduced.

Only two cassava viruses, ACMV in Africa and CCMV from Latin America have been adequately characterized. Two viruses, CBSV in last Africa and cassava veinal mosaic virus (CVMV) in Brazil, have been isolated from infected plants, but their characterization is incomplete. Of the viruslike diseases reported from Latin America, cassava frog skin disease (FSD) in the Amazon Basin, Caribbean mosaic disease (CMD) on the north coast of Colombia, and latent mosaic diseases are considered quarantine threats.

African cassava mosaic disease caused by ACMV is the most serious cassava disease on the African continent in terms of geographic distribution and economic losses. ACMV has also been found in southern India, but to date there have been no reports of its occurrence in Latin America. ACMV is a geminivirus composed of paired virus particles, 20 x 30 nm in size, containing a circular single-stranded DNA (ssDNA) genome. The virus is transmitted by the whitefly, *Bemisia tabaci*, with the rate of dissemination rapid in some regions. Recently the ACMV genome has been completely sequenced and found to consist of two circular ssDNA molecules, which are both required for infectivity. ACMV has been purified and an antiserum produced that is suitable for use in the enzyme-linked immunsorbent assay (ELISA).

CCMV, first reported from Brazil and later from Peru and Colombia, is probably present in all cassava-growing regions of Latin America. Although the incidence of CCMV infected plants is low, yield losses per plant can be as high as 60%. As there are no known vectors reported, the main means of dissemination is via infected planting material. CCMV is a member of the potexvirus group with elongated rod-shaped particles 15nm wide by 495 nm long. The virus reaches high concentrations in most host species and can be readily purified for antiserum production. Effective control measures include the use of virus-free planting material, clean propagating tools, and roguing of infected plants.

CBSV was first reported from Tanzania in 1936 and is also found in Kenya. Although severely infected roots are not marketable, the incidence and economic importance of CBSV is low in comparison to ACMV. The elongated rod-shaped particles associated with the cassava brown streak disease have an average length of 650 nm and are similar to viruses in the carlavirus group; however, their role in the etiology of the disease is still unknown.

CVMV was first reported from Brazil in 1940, but its incidence in Brazil is thought to be very low. Spherical virus particles, 40 to 50 nm in diameter, have been associated with CVMV infected plants. CVMV has been purified and an antiserum produced. The virus particles contain a doublestranded DNA genome, making CVMV a tentative member of the caulimovirus group. There are no known vectors of CVMV, and the main source of dissemination is via infected planting material. As the incidence of CVMV and field transmission are very low, roguing infected plants is the recommended control practice.

Frog skin disease was first reported from southern Colombia in 1971. Roots from infected plants are reduced in size and are usually not marketable because of the presence of deep cortical cracks or scalelike formations on the epidermis. There

602

are no distinctive symptoms on the aboveground parts of infect-
ed plants. The etiology of FSD is unknown; but elongated rod-
shaped as well as spherical viruslike particles have been ob-
served in leaf sap from infected plants. The causal agent has
not been mechanically transmitted; but it is graft transmis-
sible and can be disseminated via infected planting material.
There is inconclusive evidence that whiteflies may be involved
in field transmission.

A severe mosaic disease of cassava grown in the Caribbean
coast region of Colombia was described in 1981. A similar dis-
ease has also been reported from Cuba and Panama. Susceptible
plants are stunted with deformed curled leaves, which exhibit
a brilliant yellow mosaic. Thus, far, no viruslike particles
have been associated with the disease; however, the etiological
agent is readily graft transmissible and is disseminated via in-
fected planting material. Field transmission into plots of
healthy plants is rapid, suggesting the existence of a biologic-
al vector.

In 1982 a mosaic-producing agent was detected in several
apparently symtomless cassava clones by grafting to scions of
a susceptible indicator clone. An elongated rod-shaped virus
can be mechanically transmitted from symptomless plants. Its
role in the etiology of the disease is under investigation.


Pests

The most important pests are disseminated via stem cuttings.
The green spider mite (*M. tanajoa*), the mealybug (*P. manihotis*),
and the white scale (*A. albus*) were probably disseminated from
the Americas to other continents by this means. Of the arthro-
pods that attack cassava, those able to survive by feeding on
lateral buds on the stem are the ones that can be disseminated
on stem cuttings. The most important pests are mites, scales,
mealybugs and stemborers.

### Mites

Forty-six species of mites have been reported attacking
cassava; but in most cassava-growing regions, mites are of lit-
tle economic importance. However, under certain environmental
conditions, they can cause severe losses, reducing yields by up
to 80%. The most destructive species is the green mite *M. tana-
joa*. All the important mite species are found naturally in the
Americas, but *Tetranychus telarius* appears to be confined to
Cuba.

Mites are important in regions with extended dry periods
of three or more months. Their life cycle is very short; but
because of their high multiplication rate, populations increase

rapidly during the dry season. Mites feed on the leaves, leaving yellowish white dots. Leaf tissues are eventually destroyed; and during severe attacks, leaf fall and plant death can result. *Mononychellus* spp. feed on very young leaflets, even on buds; the nymphs are very minute and difficult to detect. Mites can easily be disseminated by interchanging stem cuttings.

## Thrips

Several species of thrips attack cassava in the Americas. The most important is *Frankliniella williamsi*, which can reduce yields by up to 28%. It could be a potentially serious pest if it were introduced into Africa and Asia. *Retithrips syriacus* affects cassava plantations in India and Australia; *Euthrips manihoti* appears to be restricted to Brazil.

When *F. williamsi* attacks the stems and petioles of cassava, the infested parts become suberized and the stem internodes are shortened. General symptoms are very similar to those of cassava viral diseases. Larvae and adults of *F. williamsi* and *F. manihoti* can survive on stem buds; thus the interchange of cassava cuttings may disseminate these pests.

## Scales

Several scale species attack cassava stems in many parts of the world. The most important species are *Aonidomytilus albus*, which is distributed worldwide, and *Saissetia* sp. A high scale population can cause serious damage to the plant. *A. albus* induces leaf fall; and when the whole stem is covered, it can reduce yield by 19%. The most important damage, however, is the reduction in the quality of planting material resulting from stem bud attack.

## Mealybugs

Severe attacks by these insects have been reported in Brazil and Colombia, as well as in Africa. Losses of up to 80% have been calculated. *Phenacoccus manihoti* and *P.herreni* attack the very young shoots first, then the petioles, and finally the expanded leaves, resulting in shortened internodes, rolled leaves and delayed development of new leaves.

Adult females move to lateral buds on the stem; therefore, cuttings from affected plants can disseminate these insects. As *P. manihoti* has only been reported in Africa, Brazil, Paraguay and Bolivia, and *P. herreni* only in Brazil and Colombia, it is advisable to take sanitary precautions to avoid their dissemination into unaffected regions.

# SANITARY MEASURES TO MINIMIZE RISK OF DISSEMINATING PATHOGENS AND PESTS THROUGH PROPAGATIVE MATERIAL

The following sanitary measures, independent of others legally established by quarantine regulations, could reduce the risk of disseminating pathogens and pests through propagative material of cassava. Their effectiveness depends on the strict application of such measures by both the donor and the recipient.

## Vegetative Propagative Material

1. The recipient country or institution must carefully analyze and evaluate the responsibilities and competence of donors as regards compliance with established quarantine regulations. Any introduction should be approved only after a careful analysis of the need and genetic advantages for such an introduction.

2. The recipient country should be cautions in the introduction of cassava propagating material from countries or areas where exotic diseases exist. For example, because of the undetermined origin of ACMV, cassava vegetative material should only be imported from Africa, India or any other country where the disease is known to be present after adequate virus indexing has been done.

3. The vegetative propagating material should be collected from plantations apparently free of systemic disease. More than one inspection should be made at the appropriate time before collecting such material in order to determine the apparent sanitary condition of the plantation. Such inspections should be made during the optimum climatic conditions for disease development; for example, during the middle to the end of the wet seasons for diseases such as CBB, superelongation and *Diplodia* stem rot, or during the optimum conditions established for the expression of viral symptoms. Before collection, vigorous, healthy plants should be identified.

4. Cassava cuttings should not be introduced to or exported from any country or any geographic region. Vegetative material should be introduced only as meristem cultures and only after sufficient tests have been carried out to determine the sanitary conditions of the introduced material. Meristems should be cut from shoots sprouted on cuttings taken from apparently healthy plants from plantations free from known viral, mycoplasmal and viruslike diseases. The cuttings should be sprouted and maintained at a high temperature for several weeks before obtaining meristems for culture to minimize the risk of

605

virus contamination. Any suspect material should be eliminat-
ed by autoclaving (120°C and 20 lb pressure for 45 min) or by
burning. All introduced materials should receive a postentry
quarantine treatment for at least a period of one year (grow-
ing cycle). During this period, the sanitary conditions of the
introduced materials should be observed carefully and periodic-
ally; at least three periodic bioassays should be carried out
in addition to any other available test that can help in the
detection of systemic diseases of cassava. It should be kept
in mind that there are mosaic-carrier varieties of cassava that
do not show any visible symptoms even though they are virus in-
fected and can therefore become the focus of dissemination of
diseases when introduced into clean areas. These diseases
could be a threat to the cassava varieties in the region and
even to other crop species. As information on systemic diseases
of cassava in relation to their identification, detection and
epidemiology is very limited, the introduction of vegetative
material should be kept at a minimum, and clones should be im-
ported only when absolutely necessary.

Botanical Seed Material

There are several seed-borne fungal and bacterial pathogens
in most of the cassava-growing areas which represent potential
quarantine risk to cassava in areas where the infested/infect-
ed material is introduced. The eradication of the CBB pathogen
from seed has been attempted by hot water and dry heat treat-
ments. However, the former treatment appears to be of low ef-
ficiency, and the latter did not control seedborne fungal pa-
thogens. It appears that the best way to avoid disseminating
cassava seed-borne pathogens can be by following these recom-
mendations carefully:

1. Collecting apparently healthy mature fruits from healthy
plants and drying them before seed removal.

2. Selecting seeds with normal size and shape.

3. Discarding seeds that float in water.

4. Treating high-density seeds (approximately 100 seeds)
in water (300 ml in a 600ml Pyrex beaker), placed centrally in
the cavity (volume 39,975 $cm^3$) of a microwave oven at full power
(1400 w heating power, 2450 MHz) for 120 sec.

5. Dusting microwave-treated seeds with Arasan (tetramethyl-
thiuran disulfide) before packing in sterile paper bags. As the
optimum temperature obtained with the microwave treatment can be
modified by several factors, the system should be set according
to the equipment available.

<u>Virus Detection Methods Available for Indexing Cassava</u>

Various virus detection techniques are currently available for indexing cassava for the presence of viruses and viruslike agents. These techniques differ considerably with respect to sensitivity, ease of manipulation, cost and labor inputs. The choice of a particular technique or combination of techniques depends on the facilities and personnel available and the level of confidence required for certifying a plant virus free. An institute involved in the shipment of cassava germplasm between continents or between countries would be expected to make the greatest effort to increase the probability of ensuring freedom from all known viruses.

Cassava virus detection methods can be based on the observation of symptoms or on the detection of virus particles and viral products. Detection based on symptomatology includes the observation of characteristic symptoms on cassava, on inoculated indicator plants, or on grafted susceptible scions. Cassava virus particles or viral products can be detected using virus-specific antiserum in the ELISA or immunosorbent electron microscopy (ISEM) tests. The isolation of double-stranded RNA (dsRNA) and nucleic acid hybridization tests permits the detection of cassava viruses without the use of virus-specific antiserum.

The reliability of detection methods based on the observation of symptoms can be increased by observing plants maintained under optimal conditions for symptom expression. For example, the symptoms of CMD are not expressed at temperatures above 28°C. In this case plants are grown in a controlled environment for symptoms development. However, in the case of FSD, root symptoms are readily apparent under field conditions. At the Centro Internacional de Agricultura Tropical, for example, the roots of plants selected for virus indexing are routinely checked for symptoms of FSD in the field; and cuttings taken from these plants are sprouted at 25 to 30°C in the glasshouse to enhance the symptom expression of other viruses. It is also possible to select apparently ACMV-free clones in Kenya based on the absence of visible mosaic symptoms.

The bioassay of mechanically transmissible cassava viruses to indicator hosts is a sensitive indexing method if a very susceptible bioassay host is available, virus concentration in the test plant is high, and environmental conditions are optimal for symtom expression. The Nigerian isolate of ACMV produces a severe, systemic infection in inoculated *Nicotiana benthamiana* plants. The Kenyan isolate of CBSV can be bioassayed on *N. debneyi*. Graft indexing is a very sensitive method if a highly susceptible indicator clone is used in the graft. The native Colombian clone Secundina has been selected at CIAT for its high susceptibility to the frog skin, Caribbean mosaic and latent diseases in Latin America. When a Secundina scion is

grafted onto an infected rootstock, a moderate to severe mosaic symptom is expressed by Secundina. Grafting provides a method for indexing viruses and viruslike agents that are not mechanically transmissible; e.g., CMD. Although a graft-indexing program requires minimal facilities and training, the procedure is labor intensive and indexing results are not available for several weeks. Another major constraint is the difficulty in maintaining virus-free stocks of the indicator clone.

Sensitive serological tests are available for indexing cassava for viruses that have been isolated, purified and an antiserum produced. ELISA is a highly sensitive, efficient and rapid method for detecting ACMV and CCMV in cassava. The immunosorbent electron microscopy (ISEM) test can also be used for detecting ACMV and CCMV. ELISA is suited to a large-scale virus-indexing program so hundreds of plants can be tested in a day with results available within 36 hours. ISEM can only be used by personnel with access to an electron microscope facility. The preparation of test material and examination of grids is simple and rapid, but the use of the electron microscope is expensive so it can only be used for a limited number of samples. Although ISEM is not as sensitive as ELISA, it has the advantage of providing a virus identification within several hours.

Nucleic acid or spot hybridization and isolation of viral specific dsRNAs have recently been applied for detecting cassava viruses. Neither test is based on the use of virus-specific antiserum. Spot hybridization has been adapted for detecting ACMV in cassava. The procedure is based on the use of a radioactively labeled DNA molecule that is complementary to the viral genome, to "probe" spots of leaf sap for the presence of viruses. The test is highly sensitive and suited for processing large number of samples. Isolation of dsRNAs as a plant virus detection method is being tested for detecting cassava viral infections. Although dsRNA molecules are not normally a component of normal plant cells, they are readily produced during the replication of many plant viruses. Therefore, the detection of dsRNA in a plant can be used as a general indicator for viral infections. This technique is particularly suitable for detecting uncharacterized viruses for which an antiserum or nucleic acid probe is not available. The extraction and analysis of dsRNA are somewhat laborious, making the test more suited for indexing a limited number of mother plants than as a general screening method.

# GENERAL CONCLUSIONS

The continued development of improved cassava hybrids through conventional plant breeding methods; the enhancement of the yield potential of native clones through thermotherapy and meristem culture; and the application of plant biotechnology to genetic improvement are increasing the amount of cassava vegetative material and botanical seeds interchanged between continents or countries. Inherent in the potential benefits to be gained from foreign material are the real risks posed by introducing exotic pathogens and pests. Hopefully, these risks can be minimized through a better understanding of the etiological agents; the development and deployment of improved eradication and indexing methods; and closer collaboration among quarantine officials and research scientists in the countries of origin and destination.

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# THE STABILITY OF PERFORMANCE OF CASSAVA GENOTYPES

J.H. Cock*

## INTRODUCTION

The more variable the conditions under which a crop is grown the greater will be the variation in its growth and yield. Generally, the more intense the management of an agricultural system the less variable are the growth conditions. For example under intense management, rice cultivated in Japan is exposed to low variation; fluctuations in water availability, fertility, and disease and pest attack as variations are minimized by irrigation and applications of fertilizers and pesticides. Cassava on the other hand is generally grown under low management levels and is subject to the uncertainty of natural rainfall patterns, to variation in soil fertility and the attack of diseases and pests during its long growth cycle. This suggests that under low level management the potential exists for much greater yield variation than under higher levels of management. Nevertheless the low resource base farmer, who generally is unable to utilize management that eliminates the causes of variability, is the least able to tolerate large fluctuations in yield or quality of his product. It is probable that the traditional farmer has developed his agricultural systems and selected his varieties with a very high priority placed on stability of yields over seasons. The farmer is mainly worried about stability over time (temporal stability); he is not generally concerned with stability of yield across geographic regions(spatial stability) although he may be interested in stability across different production systems (system stability). This latter is particularly true in cassava growing areas where different planting dates and harvesting times occur, in which cases the farmer may use different varieties and agronomic practices for each planting season or he may look for a stable system that gives good yields and quality irrespective of planting date. A research institute is, unlike the farmer however, very interested in spatial stability as the technology it develops must be applicable over large areas if a reasonable return on investment in research is to be obtained. Thus to satisfy farmer's needs and also its own re-

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quirements research centres must look to producing technology
that has, in terms of yield and quality, temporal, spatial and
system stability.  Whilst attention must be paid to these as-
pects of stability it is nevertheless obvious that not only is
it extremely difficult, if not impossible, to obtain one var-
iety or production system that has stability over all the dif-
ferent conditions under which cassava is grown, but also, it
is not necessary.  The strategy of the cassava breeding programs
must be to obtain stable production systems within defined li-
mits of variability in growing conditions and management.  In
this context the major concern, in the case of spatial stabil-
ity, is not for stability over vastly different growing condi-
tions or geographical areas (macro spatial stability) but ra-
ther for spatial stability within a relatively narrow range of
growing conditions which have to be defined (Table 1).

    The classification of these growing conditions by edaphic
and climatic parameters alone is obviously not realistic as it
is well known that a major element determining differences in
growing conditions are the biotic factors.  These biotic fac-
tors are, however, not only dependent on the climatic and eda-
phic conditions and the geographical location of a site, but
also on the cassava genotype, its management and the area plant-
ed in the particular area under consideration.  Nevertheless
the classification into edaphoclimatic zones is useful in de-
termining the gross physical environment and also to predict
which biotic factors are likely to be, or become, important
when different genotypes are grown.

    In this paper the major causes of variability or instabil-
ity are discussed with particular reference to the development
of stable genotypes.  Most examples are taken from data obtain-
ed by the cassava program at CIAT and the major testing sites
and their characteristics are described in Table 2.


FACTORS CAUSING INSTABILITY


Temperature

    There is a very strong genotype and temperature interaction
(Irikura $et$ $al$, 1979) in areas where temperature fluctuates lit-
tle from month to month.  The data available suggest that for
temperatures of less than 22°C different genotypes are required
from those well adapted to higher temperatures.  Little data
exists on the interaction between genotype and temperature when
the latter shows seasonal fluctuation.  The CIAT international
trials data obtained in the late seventies suggests that certain
clones (eg. MCol 1468, CMC 40) are well adapted to moderate tem-
peratures with little fluctuation (eg. 24°C throughout the year)

TABLE 1. CASSAVA PRODUCTION ECOSYSTEMS AND THEIR MAIN CHARACTERISTICS

| Ecosystem | General description | Temperature | Dry season duration | Annual rainfall |
|---|---|---|---|---|
| 1 | Lowland tropics with long dry season: low to moderate annual rainfall; high year-round temperature | above 22°C | 3-5 mo. | 700-2000mm (unimodal distribution) |
| 2 | Acid soil savannas; moderate to long dry season; low relative humidity during dry season. | above 22°C | 3-5 mo. | above 1200 mm (unimodal distribution) |
| 3 | Lowland tropics with no pronounced dry pronounced dry seasons; high rainfall; constant high relatice humidity. | above 22°C | absent or very short | above 2000 mm |
| 4 | Medium altitude tropics; moderate dry season and temperature | 21° - 24°C | 3-4 mo. | 1000-2000 mm (bimodal distribution |
| 5 | Cool highland areas; moderate to high rainfall. | 17° - 20°C | - | above 2000 mm |
| 6 | Subtropical areas; cool winters; fluctuating day-lengths. | Minimum 0°C | - | above 1000 mm (summer rainfall) |

TABLE 2.   SELECTED CHARACTERISTICS OF SITES FREQUENTLY MENTIONED IN THE TEXT.

| | Average Temperature °C | Rainfall mm/yr | Rainfall Distribution | Soil fertility level | pH |
|---|---|---|---|---|---|
| Media Luna | 24 | 1600 | Unimodal | Low | 6.5 |
| Caribia | 28 | 1400 | Unimodal | Medium | 6.3 |
| CIAT-Palmira | 24 | 1000 | Bimodal | High | 6.8 |
| CIAT-Quilichao | 25 | 1800 | Bimodal | Very low | 4.5 |
| Carimagua | 26 | 2000 | Unimodal | Very low | 4.4 |
| Popayán | 18 | 2100 | Bimodal | Very low | 5.5 |
| Rio Negro | 27 | 1700 | Unimodal | Low | 4.2 |
| Nataima | 28 | 1500 | Bimodal | Medium | 6.1 |
| Chigorodó | 28 | 1800 | Short dry season | High | 6.6 |
| Florencia | 25 | 2900 | Short dry season | Medium | 3.8 |
| San Martín | 25 | 2200 | Unimodal | Medium | 4.2 |

and also do well in areas where temperatures may be below 10°C for 1-3 months of the year. Few other clones have shown this adaptability, growing well only at higher constant temperatures (eg. MVen 218) or only growing well at lower constant temperatures (eg. MCol 1522). Spatial stability for temperature effects will be difficult to obtain and lines will need to be bred for the following specific temperature conditions: (1) high temperature areas with nearly constant temperatures (2) cool constant temperature zones and (3) fluctuating temperature areas.

Although cassava is not grown over such a wide range or latitudes as other crops such as rice, potatoes and beans it does in fact face a wider range of temperatures during its long growth cycle than these crops. In the case of beans and potatoes, in the subtropics, the planting season is adjusted so that the crop is grown in the cooler part of the year, whilst rice grown at higher latitudes is grown only at the warmest time of the year. The long growth cycle of cassava, in areas where temperature fluctuates markedly throughout the year, leads to a potential problem with stability across systems. If planted at different times of the year the crop will experience different temperatures at different growth periods. From a physiologycal point of view it is likely there will be a strong genotype and palnting date interaction, i.e. a potential lack of system stability.

Temporal stability with respect to temperature, may be easier to achieve. Within the tropics temperatures over the same period vary very little from year to year, and hence temperature effects are of less concern in causing temporal instability.

## Photoperiod

In the tropics large seasonal changes in photoperiod are nto found; nevertheñess, they are of sufficient magnitude to effect cassava yields, particularly at higher latitudes. Some varieties are more sensitive than others (CIAT, 1981; Veltkamp pers. comm.; Keating, 1981). Long days only effect cassava in the first three months after planting, hence change of photoperiod will only affect stability in areas where the planting season is during or immediately preceeding the long day period. Thus system and spatial stability will both be important with respect to photoperiod. It should be noted that all varieties tested so far are photoperiod sensitive in terms of such parameters as branching and dry matter distribution; neverthesless some varieties show relatively stable yields at a different photoperiods (Table 3).

## Water

The cassava plant is extremely tolerant of water stress;
nevertheless a long dry period can seriously decrease yields
(Connor, Cock and Parra, 1981). Rainfall patterns differ mark-
edly from region to region and will undoubtedly cause differen-
ces in yield to occur. Nevertheless it does seem possible to
find varieties with a stable yield response to different water
availability patterns. Thus, in a trial at Carimagua several
varieties yielded the same with or without irrigation (CIAT,
1978 1979); in Quilichao exclusion of rain from plots of MMex
59 actually increased yields, while decreasing yields of MCol
22. In both these trials, those clones with highest yield and
high harvest index were also the most sensitive to drought
stress (Fig.1). More recent trials suggest that certain var-
ieties that have stability above optimal LAI under well water-
ed conditions reduce the LAI to only slightly less than the op-
timum when a dry period occurs and that these varieties have
both high yield potential and good yield stability under vary-
ing conditions of water availability (Fig. 2)

The intensity of water stress is highly variable from re-
gion to region and from year to year hence temporal and spatial
stability are of great importance. System stability is also
important as different planting dates may subject the plant to
stress at different growth stages. It is not yet clear whether
high yielding clones are obtainable that can be planted either
at the beginning or end of the rainy season; however certain
clones (eg. CM 342-170) yielded well in Caribia and Media Luna
irrespective of planting season and others have stable starch
content (eg. Secundina) irrespective of harvest date although
the yield of the latter is relatively low as compared to new
selections (CIAT, 1981; Table 4).

## Soil

Cassava is grown on a very wide range of soils, however
it is most commonly found on those that tend to be acid and of
low fertility. Cassava is extremely stable in its response to
pH *per se* over the range of pH 4-7.5. Low pH in mineral soils
is frequently associated with high levels of Al which is toxic
to many plants. Cassava is remarkably adapted to high levels
of Al saturation and most genotypes show a stable reaction if
Al saturation is below 80% CIAT (1978, Fig. 3). In highly al-
kaline soils where salts are often a problem cassava is highly
sensitive to small changes in pH and salt concentrations with
large differences among genotypes. These areas however, are
of little or no importance for cassava production. The remark
ably high yields of MCol 1684 in several locations (Fig.4) sug-
gests that genotypes do exist that have a stable reaction to
different soils types.
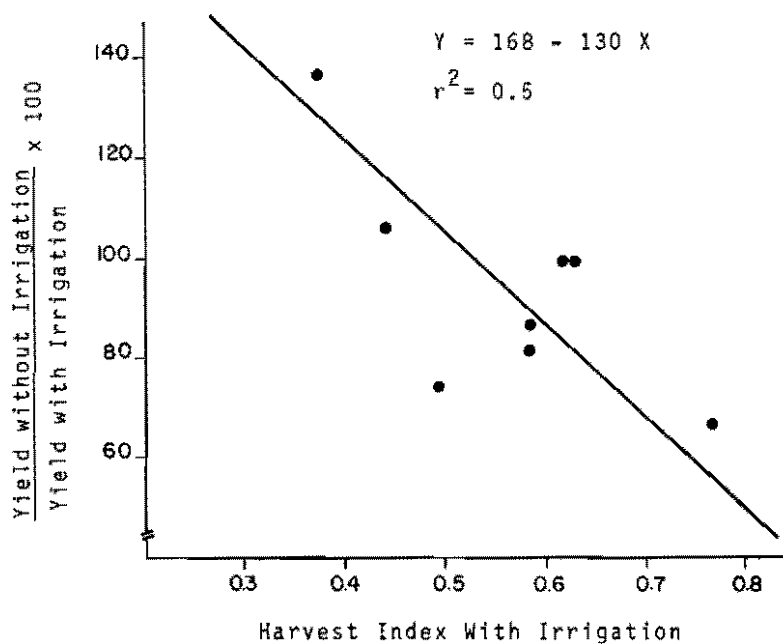
FIGURE 1.    RELATIVE YIELD WITH AND WITHOUT IRRIGATION DURING
THE DRY SEASON IN CARIMAGUA AS RELATED TO HARVEST
INDEX (Source: CIAT, 1979).
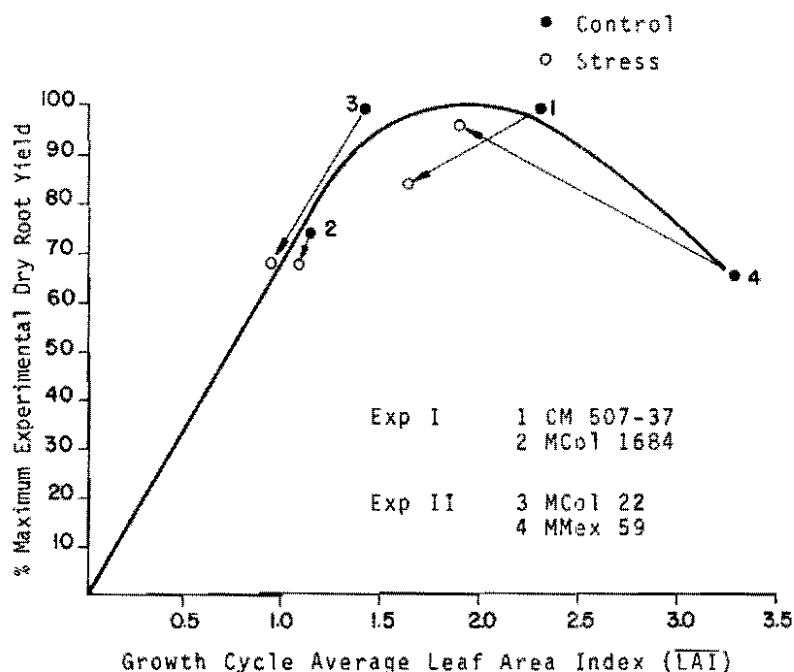
FIGURE 2.   DRY ROOT YIELD AS A FUNCTION OF GROWTH CYCLE AVERAGE
LEAF AREA INDEX (LAI) UNDER NON-STRESS AND MID-TERM
WATER STRESS CONDITIONS FOR 4 CULTIVARS WITH DIFFERENT
VIGORS.   (Source: CIAT 1984).
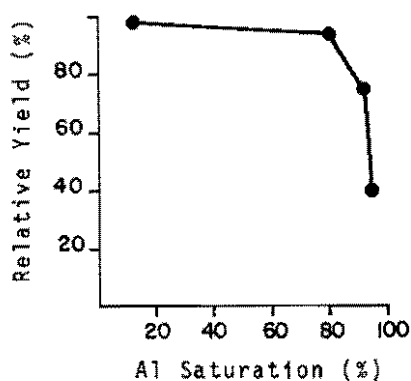
FIGURE 3.   RESPONSE OF CASSAVA TO
            DIFFERENT LEVELS OF ALU-
            MINIUM SATURATION.
            Source: CIAT (1978)
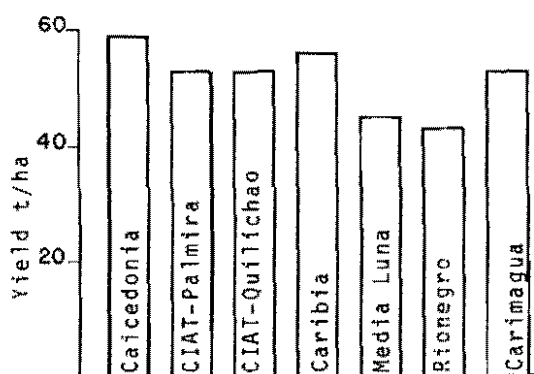
FIGURE 4. MAXIMUM YIELD OBTAINED WITH MCOL 1684
AT VARIOUS SITES WITH DIFFERENT SOIL
CHARACTERISTICS.

TABLE 3.   THE EFFECT OF LONG DAYS ON THE YIELD OF CASSAVA NINE
           MONTHS AFTER PLANTING.   YIELDS IN DRY MATTER/ha.

|            | Long days | Short days | % reduction |
|------------|-----------|------------|-------------|
| M Col 22   | 8.3       | 9.5        | 13          |
| M Col 1684 | 4.6       | 8.7        | 47          |
| M PTR 26   | 4.9       | 8.1        | 40          |

Source: CIAT


TABLE 4.   DRY MATTER YIELD (t/ha) OF CM 342-170 AT ELEVEN TO
           TWELVE MONTHS AFTER PLANTING WHEN PLANTED IN EARLY
           OR LATE RAINY SEASON IN MEDIA LUNA

|       | With fertilizer | Without fertilizer |
|-------|-----------------|--------------------|
| Early | 6.0             | 5.4                |
| Late  | 5.9             | 5.8                |

Source: CIAT, 1981

Whilst cassava shows a very stable response to different soil conditions such as pH and Al saturation, it is rather responsive to changes in fertility (Asher, Edwards, and Howeler, 1980). Fertility differences affect spatial stability, as soils vary from area to area, system stability, vecause farmers may either fertilize crops or use management practices that alter fertility, as well as temporal stability as soil fertility declines with continuous cassava cropping. Cassava has certain inherent characteristics that make it less sensitive to fertility changes than other crops (Cock and Howeler, 1978; Edwards *et al*, 1977); in addition use of chemical fertilizers and the association with mycorrhiza reduce differences in yield or quality related to fertility differences.

Several clones have now been selected that show both high yield potential and relatively stable yield at different levels of phosphorus (Table 5). Thus although yields will be higher at higher fertility levels varieties can be selected that show less yield decline at low fertility levels.

TABLE 5.  FRESH ROOT YIELD OF SEVERAL VARIETIES TOLERANT OF LOW LEVELS OF SOIL PHOSPHORUS.  (QUILICHAO, YIELD IN t/ha)

| Variety | No applied phosphorus | 75 kg P/ha applied phosphorus |
|---------|-----------------------|-------------------------------|
| M Bra 30 | 52 | 50 |
| M Bra 33 | 41 | 51 |
| CM 489-1 | 35 | 52 |
| M Col 1514 | 38 | 48 |
| CM 430-37 | 36 | 47 |

Source: CIAT (1984).

## Diseases and Pests

The effects of diseases and pests on stability are much more complex than the abiotic factors already described. The major reason for this is that the abiotic factors, in broad terms, influence the growth of the plant but the plant itself has little effect on the abiotic factors (a decline in soil fertility with continuous cropping of cassava in an obvious exception to this generalization). On the other han most of the biotic factors not only influence the growth of the plant but also their own incidence or intensity is determined by the growth of the plant and the genotype of that plant.

In addition, fluctuation or variability in abiotic factors that effect temporal stability tend to be random (eg. changes in temperature or rainfall) or follow relatively predictable trends (eg. decline in soil fertility). Experience can help us to assess the probability of fluctuations of different magnitudes in the case of random type variation and also with a few genotypes the effects on growth can be determined. Similarly controlled experiments in a small number of sites with few genotypes can enable us to predict the likely decreases in soil fertility over time. The situation with the biotic factors is entirely different; there will be random fluctuations influenced by random changes in the environment, there will also be long term trends that are partially dependent on the genotypes as well as changes in the pathogen that are extremely difficult to predict.

Diseases and pests show great variability from area to area, although certain disease and pest complexes are common to different sites within each of the major ecological zones. Phoma leaf spots are a major problem in cooler areas, in dry areas thrips and spidermites may cause severe losses in yield and quality, and CBB (*Xanthomonas manihotis*), anthracnose (*Colletotrichum* spp) and superelongation disease (*Sphaceloma manihoticola*) are major problems in the acid soil savannah areas. Our experience suggests that by adequate selection of resistant clones for each edapho-climatic zone, germplasm with microspatial stability in terms of disease and pests reaction may be obtained, and eventually, as a greater number of resistances are combined, even of macrospatial stability.

Variability in diseases and pest severity across systems may be extremely large. For example, pesticide treatment and use of "clean" planting material may delay the build up of disease and pest problems; different dates of planting may reduce the disease or pest incidence, while poor pest management may increase pest damage. All these factors point to a potentially large system instability in cassava, especially when pest control is mainly through management.

A further complication in the case of disease and pest dam-
age is that vigorous clones are able to tolerate higher levels
of damage than higher yielding but less vigorous ones, with lit-
tle change in yield or quality (Fig.5). Hence stability based
on the ability of the plant to tolerate damage with little ef-
fect on yield, may be directly related to low yield potential.
Thus, even to maintain the same levels of stability as those
possessed by low yielding varieties, which possess a large
amount of physiological redundancy, it will be necessary to in-
crease resistance levels in higher yielding genotypes.

PRESENT SITUATION IN SYSTEM, SPATIAL AND TEMPORAL STABILITY

Most breeding programs attempt to produce varieties that
given temporal stable yields and quality within a considerable
but not all inclusive spatial and system variability. When var-
ieties are needed for widely different ecosystems or production
system then different genotypes will be required, no one vari-
ety will serve for all proposes.

A SYSTEM STABILITY

The major factors effecting system stability are genotype
grown, fertility, stake selection and treatment, stake storage,
planting systems, planting and harvesting date, weed control,
cropping systems, and pest management. The reality of cassava
production systems results in use of limited input technology
which minimizes the use of irrigation, high fertilizer applica-
tions and continued use of pesticides, all of which could con-
tribute to greater staility.

Fertility Levels

Fertility levels can readily be modified by use of chemi-
cal fertilizers, which are however expensive and will probably
not be used to the extent that all differences in fertility ef-
fects on yield and quality are eliminated. Hence it is desir-
able to have genotypes and concommittant technology that are
relatively stable over different fertility levels. Mycorrhiza
may also play an important role in increasing stability in soils
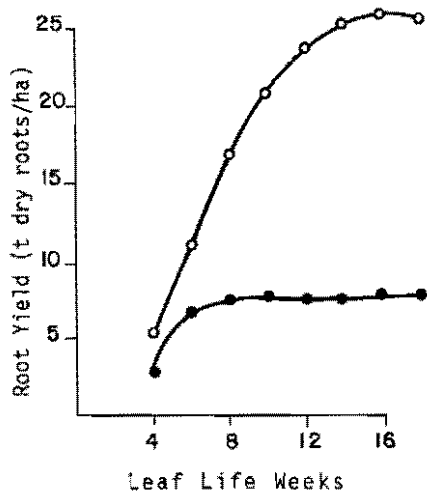of low P contents.

FIGURE 5. SIMULATED DATA ON EFFECTS
REDUCED LEAF LIFE (CAUSED
BY DISEASES AND PESTS) ON
YIELD OF A NEAR IDEAL (o)
AND A VIGOROUS PLANT TYPE
(●). Source: Cock (1978).

## Stake Selection and Treatment

Stake selection and treatment are recommended practices, nevertheless it is of interest to speculate on their effect on instability  In low stress areas such as CIAT-Palmira, high stable yields have been obtained with selected but untreated stakes; however in areas such as Carimagua, or in those areas where stakes are stored before planting, lack of treatment and selection will certainly decrease stability. Genotypic variation however exists in the ability to produce well without treatment (Table 6). and genetic tolerance to suboptimal conditions of planting material, may be sought.

TABLE 6.   PERCENTAGE GERMINATION OF SELECTED CLONES WITH AND
WITHOUT STAKE TREATMENT IN MEDIA LUNA.

| Clone | Not treated | Treated |
|-------|-------------|---------|
| MVen 25 | 93 | 95 |
| CM 681-2 | 92 | 94 |
| MCol 113 | 83 | 94 |
| MCol 1684 | 63 | 94 |
| MCol 72 | 41 | 96 |

Source:   C. Lozano, Pers. comm.


## Planting and Harvesting Date

Cassava is generally planted in the rainy season but, the planting time may be either at the beginning or the end of the rainy season.   Under Carimagua conditions planting at the end of the rainy season has given greater yields (Fig. 6), because the disease pressure is less severe during the early growth stage.   From a physiological point of view it is highly probable that stress at different periods will affect different periods will affect different genotypes differently; however it would also appear possible to obtain genotypes that give moderate yields at either planting date (Table 4).   Starch content may also be affected by planting date and harvesting date.   When
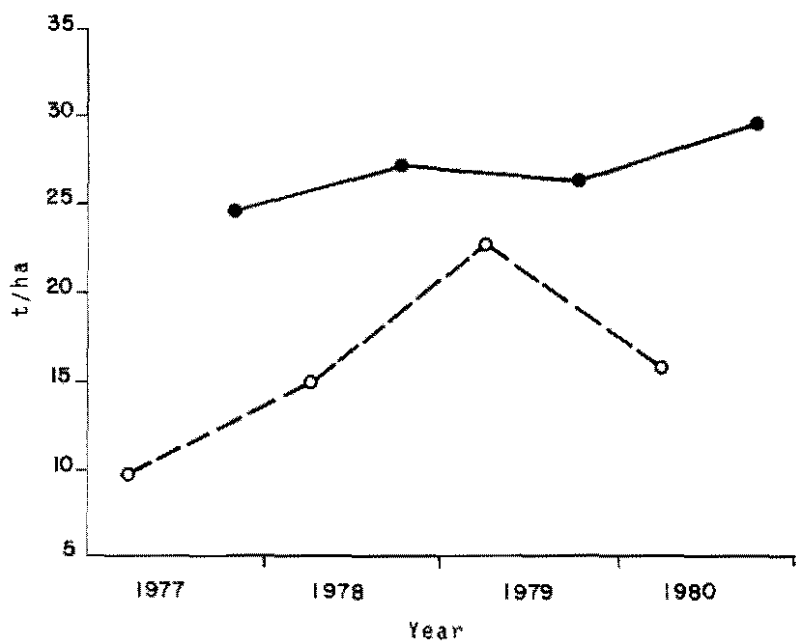
632

FIGURE 6.   MAXIMUM YIELD OBTAINED IN CARIMAGUA WITH LATE (●)
AND EARLY (o) PLANTING IN ADVANCED YIELD TRIALS.

plants of certain genotypes are harvested at the beginning of the rainy season or after a cold season starch content is very low. This effect is so great that in Thailand, many starch plants close for two months of the year when starch is at a minimum. The high starch content required for the fresh market is only applicable to about one third or less of the total cassava produced; in the other markets, although a high starch content is an advantage, the most important factor is starch yield per hectare. Nevertheless varieties exist that have high starch content (eg MVen 156, CM 523-7, Venezolana and Secundina) irrespective of harvesting time. None of these lines, however, have great yield potential, and it is not known whether it will be difficult to obtain lines with high stable starch content as well as high starch yield per hectare. It certainly seems likely that starch content declines as reserves from the roots are used to produce new foliage after the dry or cold season, and that this should later result in higher yields. Hence high yield and stability of starch content may not be compatible.

Starch content also tends to be greater when temperature us lower and vice versa. Thus in subtropical areas starch content tends to be greater in winter (Hammer pers. comm.). It is not clear whether lines exist with a stable reaction to temperature changes. In some subtropical areas cassava is planted at the beginning of winter (eg. Cuba) and in others in the Spring (eg. Rio Grande do Sur, Brazil). It is not known whether the same varieties will be effective under these very different systems, i.e. show system stability. It is quite definite that certain photoperiod sensitive lines perform poorly when planted at the beginning of summer as the are affected by long days during the first 3 months after planting. Other lines are less photoperiod sensitive and should have a more stable response.

Planting Systems

There is considerable information on cassava planting systems. Most data show little yield differences between horizontal, inclinded and vertical planting; however, there is no doubt that lodging, which can drastically reduce yield and starch content, is likely with vertical and inclined planting.

In areas with heavy rainfall root rots may become a severe problem, and planting on ridges or mounds (Lozano, 1978) was found to reduce root rots and increase stability of yield and quality.

## Cropping Systems and Management

Much of the worlds cassava, up to 40%, is grown in inter-
cropping systems and Moreno and Hart (1978) have shown a great-
er yield stability under these systems, particularly at low ma-
nagement levels (Leihner, 1979).  In case of intercropping with
short season grain legumes the same cassava genotypes yield well
in both intercropped and monoculture, suggesting that cropping
system in these cases will have no detrimental effect on yield
stability.  The starch content of the intercropped cassava is
generally less than that of the monocrop.

Differences in weed control can cause enormous differences
in yield, particularly in less vigorous cassava varieties,
which tend to have higher yield potential.  Thus in the north
coast MMex 59 showed remarkable yield stability over a wide
range of different weed control management, whereas MCol 22 was
extremely unstable.  However, highest yield was obtained with
MCol 22 under good weed control (Fig. 8).  This situation, which
also occurs with respect to other factors such as disease and
pest resistance, suggests that stability in some cases can only
be obtained as a trade off with yield potential.  Nevertheless
results from technology validation trials suggest that moderate
stable yields can be obtained over a range of different manage-
ment systems (Table 7).

## Pest Management

Certain diseases and pests can be controlled by management
practices other than host plant resistance.  The hornworm (*Ery
nnis ello*) is a good example.  Simulated damage by leaf removal
shows that the vigorous but low yielding clone MCol 113 showed
greater yield stability than the higher yielding MCol 22 (Cock
1978).  This data indicates that system stability may be confer-
red by low yielding but vigorous genotypes.  Whilst this may be
generally true it is not the case for pests that reduce germina-
tion or total plant population in the early stages.  The very
vigorous clones tend to have a narrow optimum plant population
and hence plant loss causes yield instability; on the other hand,
less vigorous types can be planted at high plant populations,
so that plant loss will have little effect on yield (Cock, 1978).

## MICROSPATIAL STABILITY

The interaction between genotype and site have made it ne-
cessary to look for specific genotypes adapted to each of the
different edapho-climatic zones defined in Table 1.  There is
still considerable  variability between sites within the same
edapho-climatic zone, but the genotypes produced should have
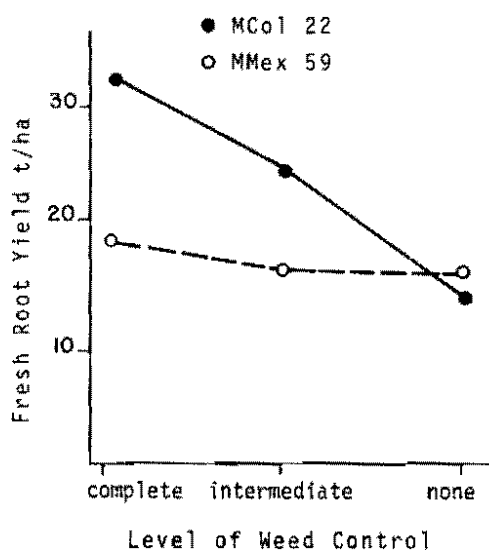
FIGURE 8. THE EFFECT OF DIFFERENT LEVELS OF WEED CONTROL ON A VIGOROUS (MMEX 59) AND LESS VIGOROUS (MCOL 22) CASSAVA CLONE. Source: CIAT (1978).

TABLE 7. COMPARISON OF DATA OBTAINED IN TRIALS MANAGED BY
SCIENTISTS (REGIONAL TRIAL) AND MANAGED BY FARMERS
WITH DIFFERENT MANAGEMENT SKILLS.

| | Regional trial | Good farmer | Poor farmer |
|---|---|---|---|
| TRADITIONAL TECHNOLOGY | | | |
| Secundina | / | 10.0 | 6.1 |
| CM 342-170 | / | 20.5 | 9.6 |
| IMPROVED TECHNOLOGY BUT NO FERTILIZER | | | |
| Secundina | 12.6 | 16.5 | 10.5 |
| CM 342-170 | 20.8 | 21.4 | 19.7 |

Source: J.K. Lynam, J.C. Toro, E. Celis and R.O. Diaz,
unpublished data.

637

relatively stable performance across different growing condi-
tions within the same edapho climatic zone (micro spatial sta-
bility).

A considerable ammount of information on microspatial sta-
bility has been obtained in the CIAT Regional Trials.  High
correlation coefficients (as well as similar yield levels) have
been obtained between dry matter yields of varieties in differ-
ent sites within the same ecological region.  In the earlier
trials, where the yield range was greater due to less rigorous
selection of lines that entered the trials, the correlation
coefficients were high for example, between Popayan and Darien
(ECZ 5) 0.94 and between Media Luna and Rionegro (ECZ 1) 0.88
with 15 and 13 varieties respectively.  Later results continue
to show high correlations between sites within each major eda-
pho-climatic zone although coefficients are lower when sites
are more different (Table 8).  A large trial established in
the north coast of Colombia with a much wider range of varie-
ties in Caribia and Media Luna showed that varieties performed
similarily in both sites.  These sites differ quite markedly
in soil characteristics and the intensity of the dry season.
These data suggest that, at least in the north coast area, mi-
crospatial stability can be obtained.  The yield level, however,
will be greater in areas with more uniform raingall and higher
soil fertility, as indicated by the consistently greater yields
in Carbia than in Media Luna.


MACROSPATIAL STABILITY


There is obviously a tremendous genotype and environment
interaction and it can not be expected that the same genotype
will perform well in all ecological regions.  Many trials show
that different genotypes are required for colder regions; how-
ever, they also indicate that broad adaptability may exist in
the warmer lower altitude areas as a small number of clones do
well in several regions.  This view is supported by the stable
yield of MCol 1684, MCol 1468 and MMex 59 over a very wide range
of edapho-climatic zones and the remarkably stable yield of CM
507-37 and stable starch content of CM 523-7 (Fig.8).  Whilst
it is true that some broadly adapted clones exist, most clones
however do not possess this broad adaptability.  Hence, bred-
ing objectives should not obtain macrospatial stability, how-
ever when it is obtained it is obviously a useful character.
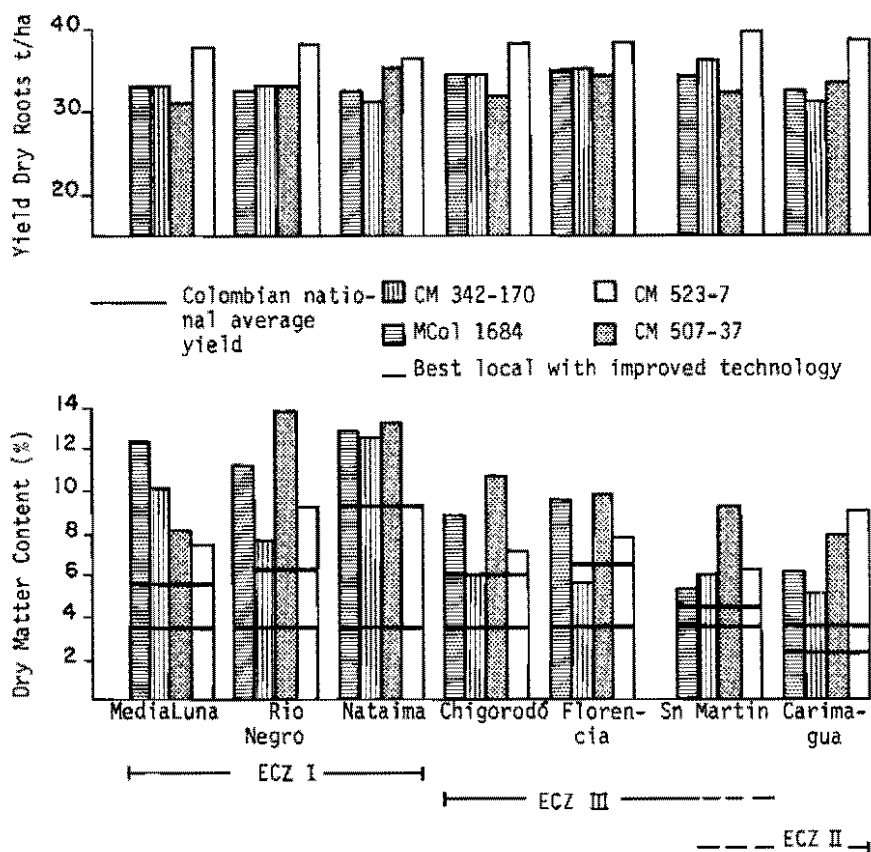
FIGURE 7.  YIELD OF DRY ROOTS AND STARCH CONTENT OF SEVERAL CLONES OVER A WIDE RANGE OF GROWING CONDITIONS.

TABLE 8. CORRELATION COEFFICIENTS BETWEEN SITES, IN THE 1980/81 REGIONAL TRIALS AND WITHIN EACH SITE
BETWEEN YEARS (1980/81 AND 1979/80), FOR DRY MATTER YIELD IN THE REGIONAL TRIALS (ONLY DATA
WHERE THERE WERE SEVEN OR MORE COMMON VARIETIES ARE USED.

| Ecosystem | | Media Luna | Rio Negro | Nataima | Chigorodó | Florencia | San Martín | Carimagua |
|---|---|---|---|---|---|---|---|---|
| 1 | Media Luna | 0.80 | 0.29** | 0.91 | 0.35 | 0.48 | 0.03 | 0.14 |
| 1 | Rio Negro | | 0.68 | 0.88 | 0.75 | 0.89 | 0.58 | 0.80 |
| 1 | Nataima | | | 0.69 | / | 0.89 | / | / |
| 1/3 | Chigorodó | | | | / | -0.07 | 0.33 | 0.46 |
| 3 | Florencia | | | | | / | 0.38 | 0.61 |
| 3 | San Martin | | | | | | 0.65 | 0.45 |
| 2 | Carimagua | | | | | | | 0.68 |

\*    Based on fresh root yields
\*\*   In other years correlation coefficients between Rio Negro and Media Luna were 0.88, 0.82, 0.70,
     0.83.
     Source: CIAT data.

TEMPORAL STABILITY

Perhaps the most difficult, and for obvious reasons, that which takes most time to ascertain is temporal stability. It has been suggested that the use of a large number of testing sites may give an idea of spatial stability and that this may be related to temporal stability. With the abiotic factors that effect stability there is a good possibility that temporal stability may be related to spatial stability. It would seem *a priori* that the effect of different rainfall patterns across sites would be similat to that within sites across time. In the case of biotic factors which may have a slow build up of intensity depending on the cassava genotypes present and on the evolution of new races of pathogens it would appear unlikely that spatial stability should be closely related to temporal stability. Whilst a variety, grown from clean seed, may yield well under stress conditions the first year, as it becomes infested with diseases and pests and debilitated by low nutrient status, its performance declines. These observations indicate, that in the case of cassava, a large number of trials in different sites can in no way replace long term trials to determine temporal stability.

Yields of the same clone may show large fluctuations in a particular site due to changes in climatic factors. Thus in Media Luna the yield of Secundina shows marked year to year variation (Table 9). The variability of the clone MVen 156 was considerably less, suggesting that there are differences in the response to climatic variation and that variability did not increase as yield increased. These differences may be due to a direct physiological response of the plant or due to secondary factors. In Popayan the clone CMC 39 shows great yield instability producing high yields in drier years and low yields in wetter years when it is severely attacked by Phoma leaf spots (Lozano *et al*, 1978). In the year following a wet year this variety yielded well and there was no long term decline in yield (Fig. 9). On the other hand, in Carimagua yields of MVen 218 declined in a year when it was attacked by CBB, and eventhough clean planting material was used in subsequent years, yields never recovered (Fig. 10). This yield decline occured at a time when total hectareage of cassava in Carimagua increased causing a marked change in the ecosystem. A similar example on a large commercial scale occured in the Campo Cerrado of Brazil with the opening of a new cassava alcohol plant in Curvelo, Minas Gerais. In the first planting local clones yielded over 20 t/ha, but as the disease and pest pressure increased yields rapidly declined to 5-6 t/ha.

The decline in yield due to a change in the ecosystem is complicated by a decline in stake quality of diseased plants. In susceptible cultivars this effect is so great that they can not survive in areas like the Llanos (Fig.11). Nevertheless,
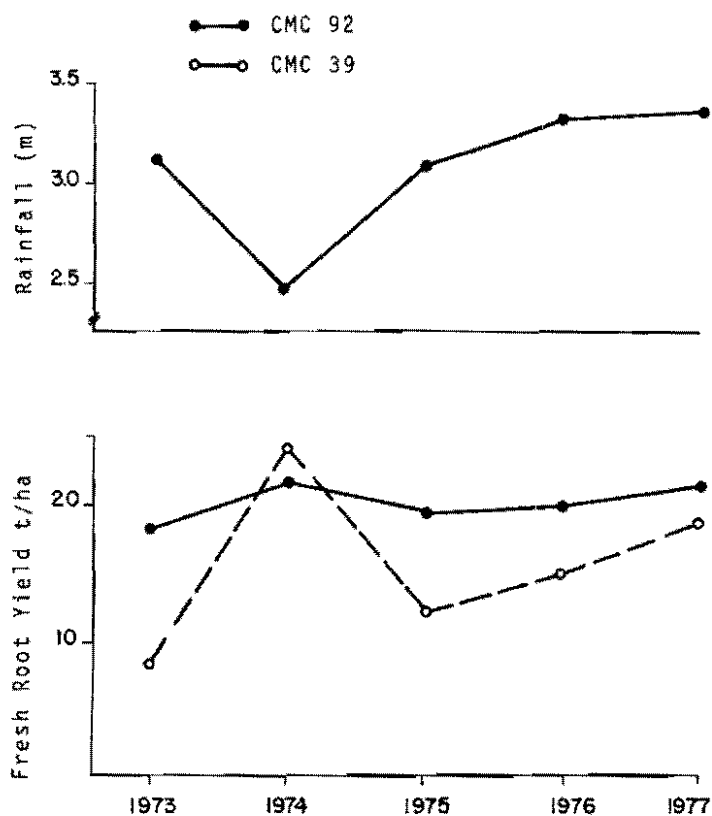
FIGURE 9.  YIELD OF TWO CASSAVA CLONES OVER SEVERAL
SEASONS AND RAINFALL DURING THE GROWTH
CYCLE.  Source: Lozano, Bellotti & Byrne.
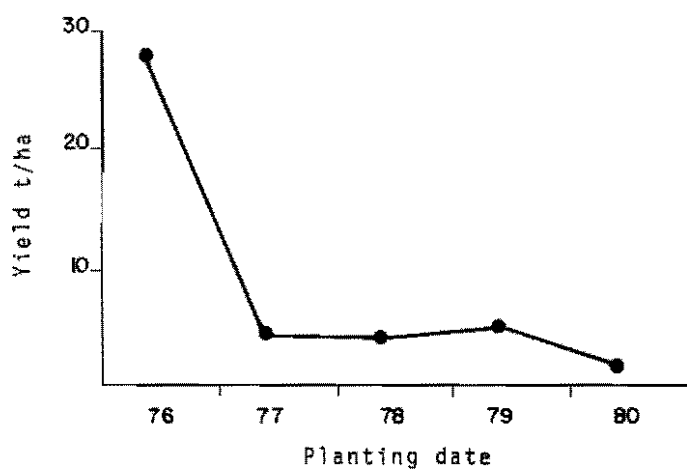
FIGURE 10.   YIELD OF HIGHLY CBB SUSCEPTIBLE CLONE
             MVEN 218 OVER SEVERAL YEARS IN CARIMA-
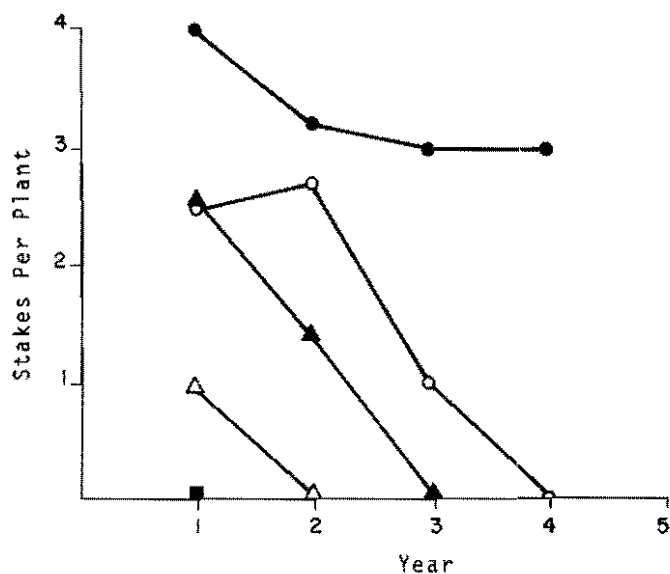             GUA

FIGURE 11.   NUMBER OF STAKES PER PLANT FROM RESISTANT (●)
MODERATELY RESISTANT (○), SLIGHTLY RESISTANT
(▲), SUSCEPTIBLE (△) AND VERY SUSCEPTIBLE (■)
OVER SEVERAL YEARS OF CONTINUOUS PRODUCTION
IN CARIMAGUA.

644

TABLE 9.    STANDARD DEVIATION AS A PERCENT OF MEAN YIELD OF
            DRY ROOTS OF SEVERAL CASSAVA LINES IN MEDIA LUNA

|  | No. of cycles | Mean yield (t/ha) | S.D. | S.D. as % Mean yield |
|---|---|---|---|---|
| MCol 1684 | 5 | 9.3 | 2.9 | 32 |
| MVen 156 | 5 | 5.5 | 1.3 | 23 |
| MCol 22 | 7 | 5.2 | 2.0 | 39 |
| Secundina | 7 | 3.4 | 1.4 | 40 |

several clones that are tolerant to the prevailing conditions
are able to maintain a steady stake production over time.  Not
only is the production of stakes important but also the capac-
ity of the resultant plants to give good yields.  In Carimagua
there is good evidence that stakes, from well adapted plants.
produced in Carimagua are as good as those produced in the re-
latively disease free environment of CIAT-Palmira (Table 10).

    These data suggest that stake production is not a major
problem if clones are tolerant of the local conditions, that
is to say well adapted varieties.  The major problem is deter-
mining quickly if a variety is well adapted to a given area.
For example in CIAT MCol 1684 was initially high yielding, how-
ever yields decreased to lower levels due to its susceptibility
to thrips.  The major challenge facing breeders at present is
to ensure that varieties that show this type of decline are eli-
minated in the selection process before release.

    In many crops a further major problem with temporal sta-
bility is the break down of resistance, particular vertical or
major gene resistance.  Robinson (1978) suggests that in a pe-
rennial crop such as cassava break down in resistance due to
new pathogenic races is uncommon.  This view is supported by
Lozano et al (1978) in spite of indications that races may
exist in the case of superelongation disease (CIATm 1977, 1980).
Even in this latter case, where there is still the possibility
of race specificity, there also appear to be other non race spe-
cific resistance mechanisms that can be exploited.

TABLE 10. YIELD FROM CARIMAGUA PRODUCED AND CIAT PRODUCED
PLANTING MATERIAL (STAKES) OF RESISTANT AND SUS-
CEPTIBLE CLONES

|  | Fresh root yield in Carimagua (t/ha) | |
| --- | --- | --- |
|  | Carimagua stakes | CIAT stakes |
| Highly susceptible | No. stakes available | 7.3 |
| Susceptible | 4.0 | 6.1 |
| Moderately resistant | 15.9 | 18.4 |
| Resistant | 17.2 | 12.3 |

In vegetatively reproduced crop "degeneration" of seed
stock with time is a common occurrence. This appears to be the
case in Secundina, planted in the Media Luna area, which has be-
come progressively infested with the "Caribbean Virus" and other
systemic factors that progressively reduce stake quality. How-
ever this progressove trend could change in relation to genoty-
pe resistance to these systemic factors. Apparently in many
clones, clean plants produced from meristem culture are much
more vigorous than either infected plants or plants that show
no symptoms but have not been cleaned by tissue culture.

The possibility of latent casual agents causing degenera-
tion, is reinformed by the fact that yields of selected F1
are generally greater than parental means. This increase, how-
ever, may be related to hybrid vigour in the progeny, not mani-
fested in the parents due to certain degree of inbreeding de-
pression. Nevertheless there is good reason to suspect that de-
generation of planting material may occur with time in many clo-
nes. However other clones have been repeatedly reproduced and
still show good yield potential whilst in some cases F1 showed
no superiority over the parental mean. These data indicate that
it may be possible to find genotypes that do not show degenera-
tion.

The clone CM 342-170, in contrast to Secundina, in Media
Luna shows no decline in yield with time indicating that it is

possible to obtain varieties that do not degenerate (Table 11).

DEVELOPMENT OF STABLE GENOTYPES

The primary centre of diversity of cassava is in South America in areas with rather acid infertile soils, particularily low in P and with high levels of Al saturation. Cassava has since been taken to a more diverse range of climatic and edaphic conditions, however until very recently it was grown mainly as a backyard subsistence crop or as a crop in shifting culture. The movement of cassava into rotational cropping systems on a commercial basis over large areas has occurred relatively recently. For example in the acid savannah areas of Brazil cassava has only been grown as a backyard crop until the last seven or eight years; in north east Thailand cassava has only become an important crop in the last ten years; rotational cropping in areas such as Media Luna, Colombia has only occurred in the last twenty or thirty years to satisfy the large recently formed urban centres, and in west Africa cassava became important in this century as soil fertility declined and shifting culture into more stationary agriculture due to land scarcity. Hence whilst cassava clones may have evolved and been selected over millenia for shifting and backyard culture it is only very recently that they have been selected for rotational or monoculture situations. From this it can be concluded that most clones will be well suited for shifting and subsistence culture, but that there is considerable room for improvement in terms of stable high yields of good quality product in stationary agriculture.

Farmers and research agencies have undoubtedly made progress in selection, thus for example MCol 1468 (CMC 40) yields well over a wide range of conditions but tends to be very thrips susceptible and low in starch content; Secundina and Venezolana on the north coast have obviously been selected largely on the basis of eating quality as until very recently without good quality the product was completely unsaleable; and Rayong 1, grown on more than a million hectares in Thailand, for yield whilst being relatively low in starch and susceptible to various diseases. The world germplasm collection at CIAT reflects the level of selection. In the Llanos Orientales local clones are successfully grown at the backyard level with CBB superelongation attack either avoided or at a low level and yet the collection from the Llanos Orientales shows an extremely low frecuency of highly resistant clones suitable for more extensive cultivation (Table 12).

The basis for the development of genotypes with a stable reaction to different growing conditions over system, space and time is the available germplasm. In the case of CIAT this

TABLE 11.  YIELD OF TWO CLONES WITH SUCCEDDING GENERATIONS OF
PLANTING MATERIAL.  (CLONES WERE INITIALLY CLEANED
BY TISSUE CULTURE TECHNIQUES).

| Generations since cleaning | Yield (t/ha) Secundina | CM 342-170 |
|:---:|:---:|:---:|
| 1 | 30 | 24 |
| 2 | 26 | 24 |
| 3 | 21 | 22 |
| 4 | 18 | 23 |

Source: CIAT, 1984

based on some 3700 clones collected from farmers fields through-
out Latin America with the widest genetic variability possible.
This basic germplasm is then evaluated in the different edapho-
climatic zones.  Germplasm with useful characters is then either
used directly for crosses aimed at producing directly new culti-
vars, or placed in crossing blocks with the objective of produc-
ing elite germplasm that has even higher levels of resistance
or tolerance to such factors as diseases, pests, Al and low nu-
trient status,  than the initial germplasm selections.  These
elite germplasm with useful characters are crossed to produce
large numbers of hybrid seeds.  The selection of parents is made
in the different edapho-climatic zones but the crosses are made
centrally at a site with a favourable environment for flowering
and seed production.

The initial selection from seedling plants is mainly direct-
ed to eliminate obviously suitable material and this is done at
CIAT.  The good correlation between yield and harvest index at
all sites and the good correlation between harvest index at CIAT
and Caribia, Carimagua and Media Luna in the absence of heavy
disease pressure suggests that his system is valid for at least
removing lines of low yield potential (Popayan, the highland
testing site used by CIAT) is very distinct and seedling plants
are selected at that site).  Attempts to grow seedling plants
directly in the higher stress sites has not been as successful
because the seedlings are so weak compared to stake produced
plants that they may be killed off before they have a chance to

TABLE 12.  FRECUENCY OF GERMPLASM ACCESSIONS COLLECTED IN THE LLANOS OF COLOMBIA WHICH DEMOSTRATE COMBINED RESISTANCE TO ENDEMIC PATHOGENS AND PESTS

| Character evaluated | Level of expression | Frecuency | Percent |
|---|---|---|---|
| CBB | $\leq 3$ | 36 | 36 |
| Plus superelongation | $\leq 3$ | 29 | 29 |
| Plus *mononychellus* mitte | $\leq 3$ | 16 | 16 |
| Plus *Vatiga* lace bug | $\leq 3$ | 14 | 14 |

Source: C. Hershey, Pers. comm.

prove themselves.  After intial, and not very rigorous selection, stakes are planted in the zone for which the cross was made for evalaution.  At this stage plants are grown with a level of management that the "average" farmer should be ablt to emulate. Whilst thei may not necessarily ensure system stability it does mean that if the cultivar finally produced is system unstable then the farmer can readily modify his system in such a manner that the particular genotype is of value.  CIAT has also, fixed the management level as low input.  Hence the selection is also done at low levels of fertilizer applications with no post planting use of pesticides.

After the first year selected material is replanted using locally produced planting material in each edapho-ecological zone.  After three years in the same site advanced lines, which must by now have shown a certain degree of temporal stability pass to the regional trials network and continue in the advanced yield trials for further evaluation of performance.

VARIETAL RELEASE IN CASSAVA

Cassava has a low rate of propagation and a long growth cycle.  A direct result of this is that it will take a long time to change to a new variety in traditional growing areas.  This

means that it will not be possible in cassava, as in crops
such as rice, to rapidly introduce to traditional growing areas
new varieties and the change them for improved ones, if and when
they prove unsatisfactory. Cognizance of this has resulted in
extreme caution on the part of the cassava program in pushing
new materials without a very extended testing period in the
field. However there are several reasons why it may not be ne-
cessary to excercise such extreme caution in the future.

One of the main fears of introducing a variety without a
very long period of testing in the field is that problems will
airse with temporal stability, mainly due to diseases and pests,
that cannot be prognosticated in short term testing. This fear
would be well founded, if massive increases in planting material
were envisaged in order to open up a new area for cassava culti-
vation because the area would probably initially be relatively
disease and pest free and hence problems would take time to ap-
pear and secondly a new variety would be introduced without far-
mers having an extended time period to evaluate it.

In areas where cassava is presently grown, for example the
north coast of Colombia, the situation is different. Farmers
have a long tradition of changing to new lines. Thus "Blanca
MOna" was almost entirely replaced by "Secundina" in the late
seventies and now this is slowly being replaced by "Venezolana".
The replacement rate is slow and farmers evaluate the new lines
whilst they are multiplying them. Even if they become over-en-
thusiastic about a new line, the slow rate of porpagation prev-
ents them from making a precipitate change to the new material.
This suggests that in an area of small farmers where cassava is
a traditional crop, distribution to each farmer of a small
amount of planting material, of lines in a fairly early stage
of selection carries little danger of causing problems even if
the variety later fails. Perhaps the only real danger is loss
of credibility with the farmer. However if the new line is giv-
en "as something to try" and the new agronomic practices are the
main recommendation loss of credibility can be minimized.

If the arguments stated above are accepted and also the
fact that promising materials exist with good yield and starch
content, these should be actively distributed to farmers. If
at each regional trial 1000 stakes of the most promising materi-
al were given to ten farmers (100 stakes each) then each farmer
could be expected to reach a maximum of 1 ha each after three
years assuming the variety was well accepted by the farmers.
By observing the performance on the farms for three years, in-
formation ccould be obatined to help to make the decision to
formally release the new variety and instigate more intensive
propagation.

When new varieties are to be introduced to a non-tradition-
al cassava growing area the situation is completely different.

650

Thus in Mexico where cassava is being rapidly propagated on a
masive scale to open up new areas, there is a real danger of
varieties having severe problems after a few years.  In these
cases two approaches seem to be of paramount importance.  First-
ly, to maintain a broad germplasm base with several different
lines under multiplication, and secondly, a very careful study
of changing disease and pest populations during the multiplica-
tion phase.


CONCLUSIONS


        Stability of yield over time (temporal stability) and
across management practices (system stability) are important to
the farmer whilst stability within major classifications of eco-
logical region (microspatial stability) is essential and across
major edapho-climatic zones (macro spatial stability) is desir-
able as to maximize the applicability of research results.


Temporal Stability

        The generally high correlations between yield of the same
genotypes across years in several different sites (Table 8) sug-
gests that the same genotypes that are superior in one year will
continue to show superiority relative to the others over time,
even though absolute yield levels may fluctuate.

        A major problem with temporal stability is the slow build
up of disease or pest pressure and which causes degeneration of
planting material with time.  Certain clones with a broad resis-
tance to disease and pests appear to be capable of producing
good quality planting material and maintaining yields over long
periods.  Break down of genetic resistance as a factor reducing
stability does not appear likely to be a major problem in cassa-
va.  Little is known about the problems of degeneration of plant-
ing material, nevertheless certain clones have been reproduced
over hundreds oc cycles and are still highly productive, so
stability can obviously be obtained.


System Stability

        Most cassava is produced and will be produced with low in-
put technology.  The philosophy adopted to obtain system stabil-
ity is to fix a set of management practices readily achievable
by farmers and select clones for these practices.  Selected clo-
nes are then evaluated under farmers' management practices and
their stability assessed.  The data collected so far do suggests
that relatively system stable cultivars can be obtained.  Never-
theless in cassava production with extremely poor agronomy addi-

tional yield stability may be conferred only by physiological redundancy which requires a sacrifice of yield potential under good agronomy. It does not appear necessary to think of different genotypes for mixed and monoculture with short growth cycle intercrop (less than 100 days).

## Microspatial Stability

In general there are good correlations between the yield performance, with similar management, of lines between sites within the same edapho-climatic zones (Table 8). Microspatial stability is unlikely to be a major problem.

## Macrospatial Stability

Areas with maximum mean monthly temperatures, below 22°C will need specific genotypes. The adaptability of tropical clones to areas with a cool winter is not well established. Nevertheless the extremely stable yield performance of certain lines and the high starch content of others across edapho-climatic zones I, II, III suggests that stability across macro zones may be found in a limited number of lines.

## ACKNOWLEDGMENTS

# CHAPTER V


# PROCESSING AND UTILIZATION


POST-HARVEST DETERIORATION OF CASSAVA ROOTS

STORAGE OF CASSAVA ROOTS FOR ANIMAL CONSUMPTION

CASSAVA ROOT PROCESSING FOR ANIMAL NUTRITION

UTILIZATION OF CASSAVA ROOTS AND PRODUCTS IN
ANIMAL FEEDING.

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# POST-HARVEST DETERIORATION OF CASSAVA ROOTS

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## INTRODUCTION

Cassava is one of the basic crops of tropical regions, and constitutes more than 50% of total root and tuber production in these areas (Booth, 1974). World cassava production in 1980 reached a total of 122 million tons (FAO, 1981). It has been estimated (Phillips, 1974) that cassava supplies 39, 12 and 7% of calorie requirements in the diet of the population of Africa, Latin America and the Far East, respectively. One of the principal limitations to increasing cassava consumption in the human diet is the short post-harvest life of the storage roots; these deteriorate rapidly, greatly reducing their quality and consequently becoming unacceptable as a human food and for a variety of other uses.

During recent years several national and international institutions have conducted research aimed at determining the causes of post harvest deterioration of cassava roots. In addition, pre-and post-harvest treatments to reduce the perishability have been studied and storage systems developed.

This chapter will review the different aspects related to cassava post-harvest deterioration, and the following chapter will sumarize treatments developed to extend the post-harvest life of the roots and describe the storage systems developed recently.

## POST HARVEST DETERIORATION

The most important part of the cassava storage root is the pulp or parenchyma (the edible portition) where the starch resources of the plant are concentrated. The parenchyma contains xylem vessels distributed in the form of streaks. The centre of the

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root contains the core of fibrous xylogen, while the perifery of the root contains layers of phloem, schlerenchyma and perderm which form the peel (Fig. 1).

The symptoms of deterioration appear during the first three days after harvest as a discoloration of the parenchyma and xylem vessels. The discoloration is initially of a blue or blue-black color, later turning brown, in the form of vascular streaks which can be clearly seen in longitudinal sections of the roots (Montaldo, 1973). The streaks can take on a black colour, caused by a darkening of the xylem vessel walls and the appearance of occlusions of parenchymatic origin within them (Rickard, 1982). The changes in colour spread to parenchymal cells, which turn a bluish colour (Averre, 1967) and also show signs of desiccation.

The initiation and subsequent degree of deterioration is closely related to the presence of mechanical damage, which commonly occurs at the time of harvest. Some varietal characteristics (root length, presence of long peduncles, etc); the texture and degree of compaction of the soil and the method of harvest (manual or mechanical) are some of the factors which affect the incidence of root mechanical damage (Cock $et$ $al$, 1978). The proximal and distal regions of the root are the most likely to suffer mechanical damage. The degree of adhesion of the peel layer to the parenchyma will also determine the degree of mechanical damage occasioned during both harvest and later transportation of the roots. For these reasons the first symptoms of deterioration are usually observed in regions when the peel has been damaged or lost, or in the proximal and distal ends of the root.

In addition to discoloration described above, roots can also be attacked by a range of micro-organisms which produce root rots 5 to 7 days after harvest (Booth,1976; Lozano $et$ $al$ 1978). The blue black vascular streaks are also apparent in this case, but spreading outwards from the areas of rotting and not associated with areas of mechanical damage.

Research conducted to date allows these two types of deterioration to be distinguished and diferentiated. They have been named primary or physiological deterioration and secondary or microbial deterioration (Booth, 1974, 1976; Rickard and Coursey, 1981). Physiological deterioration is characterised by blueblack or brown vascular streaks, concentrated in a ring around the perifery of the parenchyma and associated with mechanical damage. Microbial deterioration occurs subsequent to the development of physiological deterioration and is characterised by microbial rotting, caused by a range of fungal and/or microbial wound pathogens.

The two types of deterioration are illustrated in Figure 2, in which physiological deterioration can be observed as a
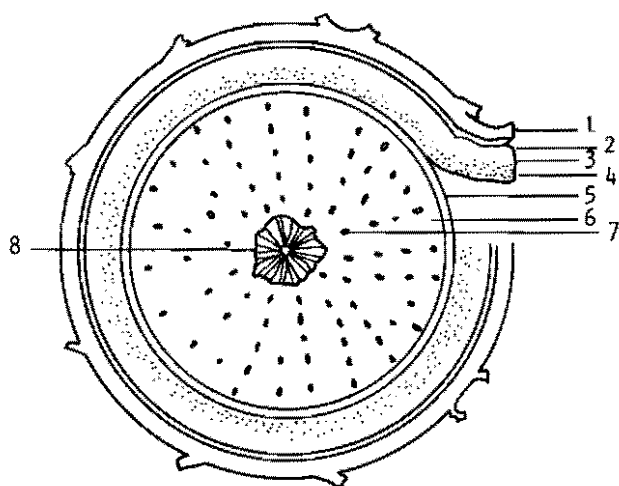
1. Periderm or bark
2. Schlerenchyma
3. Cortical parenchyma
4. Phloem
   (1 to 4 = peel)
5. Cambium
6. Parenchyma (starch reserves)
7. Xylem vessels
8. Xylem bundles and fibers

FIGURE 1.   TRANSVERSE SECTION OF CASSAVA ROOT.   (HUNT *et al*, 1977).

FIGURE 2.   PHYSIOLOGICAL DETERIORATION (PRIMARY) AND
            MICROBIAL DETERIORATION (SECONDARY) OF
            CASSAVA ROOTS

TABLE 1.   COMPARISON OF THE SUSCEPTIBILITY OF ROOTS OF TWO CLONES OF CASSAVA TO PHYSIO-
LOGICAL DETERIORATION

| Clone | Days after harvest | Distance from proximal end (cm) | | | | | | | Deterioration Percentage |
| | | 2 | 4 | 6 | 8 | 10 | 12 | 14 | |
|---|---|---|---|---|---|---|---|---|---|
| MCol 22 | 1 | 0* | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 9 | 9 | 8 | 7 | 6 | 3.5 | 1.75 | 63.2 |
| | 3 | 10 | 10 | 9.75 | 9.5 | 8.75 | 8 | 5.50 | 87.9 |
| | 4 | 9.75 | 9.75 | 7 | 6.75 | 5.75 | 4.75 | 2.25 | 62.5 |
| MCol 113 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 2 | 4 | 3.5 | 2.25 | 0 | 0 | 0 | 0 | 13.9 |
| | 3 | 8 | 4.75 | 1.50 | 0.25 | 0 | 0 | 0 | 20.7 |
| | 4 | 7 | 3.75 | 2.50 | 1.75 | 1.75 | 1.75 | 0 | 28.9 |

*   Mean of sections of 4 roots evaluated on a scale of 0 to 10.

ring of streaks and dessicated cells around the perifery of
the parenchyma, while this organisation is absent from the
streaks produced as a result of microbial deterioration where
the maceration of tissues affected by rotting is also prominent
(Lozano *et al*, 1978).

It has been conclusively demonstrated that the two types
of deterioration are due to distinct processes (Averre, 1967
Passam and Noon, 1977; Noon and Booth, 1977). No microorganisms
have been isolated from tissues affected by physiological dete-
rioration, while the following have been isolated from the ad-
vancing margin of secondary deterioration: *Penicillium*, *Aspergi-
llus*, *Rhizopus*, *Fusarium*, amongst others.

## EVALUATION OF SUSCEPTIBILITY TO PHYSIOLOGICAL DETERIORATION

The perishability of cassava roots is one of the most im-
portant factors affecting their marketing and commercialization.
Therefore it is important to evaluate the degree of susceptibil-
ity to post-harvest physiological deterioration of different cul-
tivars, etc. For this, it is necessary to standardise some fac-
tors which affect the development of physiological deterioration,
such as the level of mechanical damage and microbial contamina-
tion and also ensure a consistent storage environment.

A subjective method, based on the work of Marriot *et al*
(1978) to evaluate storage roots for susceptibility to phsiolo-
gy deterioration has been developed by the CIAT/TDRI Cassava
Storage Project. The details of this methodology are described
here:

1. Select commercially - sized roots with a minimum length
of 18 cm, without mechanical damage (except at the two ends) and
with no pre-harvest rotting visible.

2. Discard the proximal and distal root ends, cutting at
15 cm long root section.

3. Cover the distal end of the 15 cm long root section
with a square of PVC film in order to maintain the moisture
content of the distal root tissues, and hence inhibit the deve-
lopment of deterioration from this end of the section (Fig. 3).
In this way, physiological deterioration develops only from the
proximal cut end of the section, where loss of tissue moisture
does occur.

4. Store roots in a place protected from direct sun, rain
and rodents, but exposed to ambient air. It is not advisable
to store these root sections in bags, due to changes in humi-
dity which can affect the development of physiological deterio-
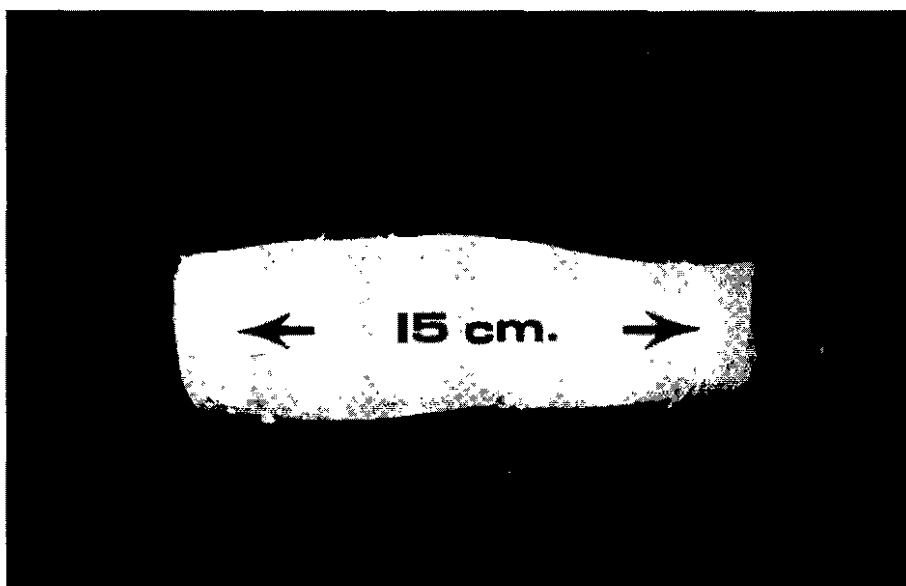tation.

660

FIGURE 3.   15 CM ROOT SECTION, USED FOR THE EVALUATION
            OF PHYSIOLOGICAL DETERIORATION

5. Evaluate root sections after three days of storage, sufficient time for physiological deterioration to develop but insufficient for microbial deterioration to have initiated. The evaluation is carried out as follows:

a. cut transverse slices 2, 4, 6, 8, 10, 12 and 14 cm from the proximal end, giving a total of seven slices.

b. assign values on a scale of 0 to 10 according to the degree of physiological deterioration on the proximal side of each slice. The values on the scale correspond to the percentage of the surface deteriorated (eg. value 1 = 10%, 2 = 20% etc). Normally, only the perifery of the parenchyma is considered, since the central tissues rarely deteriorate (Fig. 4 a,b).

Physiological deterioration intitates from the proximal end of the 15 cm root section. Roots very susceptible to deterioration develop the characteristic streaks up to the last slice evaluated ie reaching the distal extreme of the section. Roots with less susceptibility to physiological deterioration develop symptoms in the slices close to the proximal end of the section only,with none reaching the distal end.

Ten or twenty roots per clone or treatment are normally evaluated. The results are expressed as the mean of the seven scores, per root section, and the mean of the individual section scores for each group of 10 or 20 roots can then be calculated. The maximum deterioration score of each root section is 70 (100 % of the surface deteriorated for each of the seven slices). This can be converted to a pecentage; the mean percentage per treatment/clone is called the "Deterioration Percentage" (Wheatley, 1982).

Table 1 gives some typical results obtained using this evaluation methodology for physiological deterioration in roots of two clones, MCol 22 and MCol 113. MCol 22 roots are more susceptible to physiological deterioration than those of MCol 113 according to these results. In order to extrapolate these results to more "real" conditions, the evaluation of physiological and microbial deteriorations together in whole roots can be carried out. This requires observations after one or two weeks of storage, allowing time for the secondary deterioration to develop. It is important here also to standardise conditions as much as possible, although the use of whole roots with differing degree of damage is necessary.
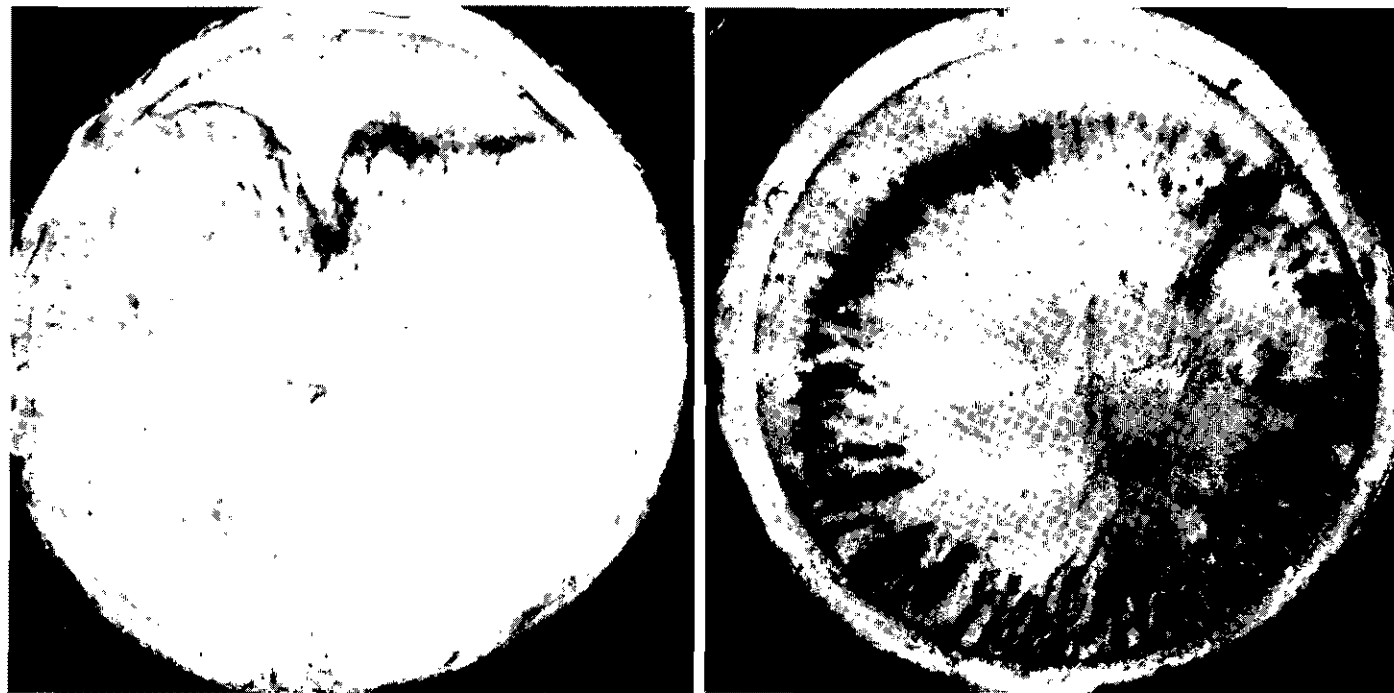
FIGURE 4. TRANSVERSE SLICES OF CASSAVA ROOTS SHOWING SCORES OF 2 (a) AND 10 (b) OF PHYSIOLOGICAL DETERIORATION.

## CAUSES OF PHYSIOLOGICAL DETERIORATIONS

The mechanisms responsible for physiological deterioration have been little studied until recently, when research on this subject has indicated the involvement of complex biochemical reactions.

Post-harvest root treatments, such as immersion in hot water (Averre, 1967; Montaldo, 1973), storage in a low-oxygen environment or in an atmosphere of $CO_2$ (Noon and Booth, 1977) inhibit the development of physiological deterioration and suggest the involvement of enzymes such as peroxidases (Czyhrinciw and Jaffe, 1951) in the process. Total root peroxidase activity does increase after the initiation of physiological deterioration (Marriott *et al*, 1980).

Some environmental conditions, such as temperature and relative humidity affect the development of physiological deterioration, especially when associated with mechanical damage (Marriott *et al*, 1979). Cassava roots with mechanical damage stored in an environment of low humidity (65-80%) deteriorate more rapidly than those maintained in 100% RH. Tissue respiration was maintained at a higher level in the low RH environment. These results show the critical effect that water loss from damaged tissues can have on deterioration.

Cytological studies and electron microscope observations have demonstrated that the discoloration occurring in physiological deterioration constitutes a damage or wound response by the root tissues, which does not remain localised but spreads rapidly through the root (Rickard¹, 1982).

The inital response occurs as occlusions of the xylem vessels and the production of fluorescent compounds in the parenchyma tissues. The occlusions contain carbohydrate, lipids and compounds similar to lignin. In the initial stages free phenolic compounds, leucoanthocyanins and catechins are found in the xylem vessels. The blue and black pigments appear to be condensed tannins derived from these compounds (Rickard, 1982).

The compound with greatest fluorescence has been identified as scopoletin, a coumarin (Rickard, 1982; Wheatley, 1982). Scopoletic is present in very low concentrations in fresh roots but increases considerably (from <1.0 to >250μg/g dry matter) within 24 hours after harvest (Wheatley, 1982). This drastic increase allows the visualization of scopoletin in the tissues when observed under ultraviolet light, due to its intense fluorescence. The application of scopoletin to fresh tissues rapidly induced the symptoms of physiological deterioration. Roots resistant to physiological deterioration were found to accumulate less scopoletin than susceptible roots (Wheatley, 1982).

In spite of the advance in our knowledge of physiological deterioration, the specific biochemical mechanisms which lead to the formation of scopoletin and the appearance of deterioration are still unknown.

## FACTORS WHICH AFFECT CASSAVA ROOT SUSCEPTIBILITY TO PHYSIOLOGICAL DETERIORATION

### Varietal differences

Evaluations of the susceptibility of different cassava varieties to physiological deterioration have shown that great differences exist (Montaldo, 1973; Pereira, 1977; CIAT, 1976, 1977; Lozano *et al*, 1978). Of 65 cultivars evaluated, Montaldo (1973) found two which showed no signs of deterioration seven days after harvest, 11 with very little, 45 with moderate susceptibility and 7 very susceptible. The evaluation of CIAT's cassava germplasm bank for root durability 7 days after harvest (ie physiological + microbial deterioration) showed a wide range of values for both types of deterioration (CIAT, 1976, 1977). In these studies a positive correlation between the root dry matter content and the degree of physiological deterioration was found. This relationship complicates breeding for high dry matter content and resistance to physiological deterioration simultaneously.

In addition to the inter-varietal variation described above there also exists intra-varietal variation. Figure 5 shows the results of evaluations of four cultivars carried out in CIAT between 1979-1980. The Deterioration Percentage in the roots of cultivar MCol 22 varied from less than 20% to more than 90%, showing that this cultivar can be resistant or susceptible to physiological deterioration according to conditions at or before harvest. Since genetic factors are not the only ones which determine the susceptibility or resistance of clones to physiological deterioration, it is difficult to express an absolute degree of susceptibility for each clone studied.

### Edaphoclimatic Conditions

Evaluations of physiological deterioration of various cassava clones each harvested in five sites in Colombia with different edaphoclimatic characteristics have demonstrated the effect that these conditions can have on the susceptibility to physiological deterioration (Table 2). The Deterioration Percentage of each clone varied significantly between the sites studied. In CIAT-Palmira and in Popayán a wide range of values was obtained but in the remaining sites the level of deteriora-

TABLE 2. REPRESENTATIVE RESULTS OF EVALUATIONS OF PHYSIOLOGICAL DETERIORATION CARRIED OUT IN FIVE SITES IN COLOMBIA (1980).

| Cultivar | C I A T (Valle del Cauca) | Popayan (Cauca) | Media Luna (north coast) | Caribia (north coast) | Carimagua (eastern plains) |
|---|---|---|---|---|---|
| | Percentage of Deterioration | | | | |
| MCol 22 | 90.1 | 3.8 | 1.4 | 1.7 | 0.0 |
| MCol 72 | 50.2 | 2.3 | 1.4 | 1.1 | 4.0 |
| MCol 1684 | 12.7 | 3.6 | 1.3 | 6.5 | 1.6 |
| MPan 19 | 5.7 | 30.9 | 2.5 | 26.9 | 0.1 |
| CM 305-122 | 69.9 | 62.9 | 3.7 | 2.9 | 0.3 |
| CM 305-120 | 32.4 | 9.3 | 1.8 | 1.7 | 0.0 |
| MVen 77 | 3.0 | 24.7 | 1.6 | 6.9 | 0.3 |
| MPan 114 | 2.1 | 5.9 | 0.4 | 1.0 | 0.0 |
| Sata Dovio[1] | 12.6 | 72.0 | 2.7 | 0.2 | 0.0 |
| Secundina[2] | 58.6 | --[3] | 1.9 | 24.0 | --[3] |

[1] Native cultivar, Popayan
[2] Native cultivar, north coast
[3] No roots produced

tion was significantly less, with the clones grown in Carimagua being completely resistant. Evaluations of roots after six days gave similar results to those of the standard three day evalaution at Carimagua.

In this study a positive correlation was found between root dry matter content and physiological deterioration only in CIAT-Palmira and Popayan, the two sites where high Deterioration Percentages were found (Table 3).

TABLE 3.   CORRELATION COEFFICIENTS BETWEEN PHYSIOLOGICAL DETE-
           RIOTATION AND DRY MATTER CONTENT IN THE FIVE COLOM-
           BIAN SITES.

| Site | n | Correlation coefficient, r | Significance level |
|------|---|---------------------------|--------------------|
| CIAT-Palmira | 26 | 0.68 | 0.1% |
| Popayan | 23 | 0.56 | 1.0% |
| Media Luna | 26 | 0.34 | ns |
| Caribia | 25 | 0.37 | 10.0% |
| Carimagua | 23 | 0.26 | ns |

Although a given cultivar can be considered susceptible or resistant to physiological deterioration in a given site, its behavior may change with time, possibly as a consequence of changing climatic conditions. Table 4 shows the results of evaluations of six clones (three local cultivars and three non-adapted clones) in Popayan. The local adapted cultivars were more susceptible to physiological deterioration than the other clones, and the deterioration was greater in September than at other times of the year.

Observations made during the course of these studies indicated that plants of the clones most affected by "negative production factors" (ie insect and disease problems; drought, etc) suffered more defoliation and had more resistance to physiological deterioration than the other clones (Wheatley, 1982). This indirect evidence implies that the negative production factors

which produce defoliation before harvest and reduce root dry matter content, on the other hand also induce resistance to physiological deterioration. Experiments with plants defoliated manually have confirmed this conclusion. Thus the pre-harvest environment can have a great effect on post-harvest root deterioration and well adapted clones can be expected to be more susceptible to physiological deterioration than ill-adapted clones for a given region.

TABLE 4. EFFECT OF HARVEST DATE OF SIX CASSAVA CULTIVARS ON ROOT PHYSIOLOGICAL DETERIORATION - POPAYAN, 1980.

| Cultivar | Month of harvest | | | |
| | March | April | July | September |
|---|---|---|---|---|
| Amarilla (local) | 7.7 | 10.1 | 82.6 | 84.1 |
| Negrita (local) | 1.9 | 31.9 | 34.3 | 80.7 |
| CMC-92 (local) | 3.6 | 11.1 | 33.3 | 78.6 |
| MMex 59 | -* | 6.3 | 2.1 | 6.0 |
| MCol 22 | - | - | 4.0 | 0.0 |
| MCol 1684 | - | - | 3.9 | 2.9 |

*   Insufficient roots for evaluation

The Effect of Pre-harvest Prunning

In some Latin American cassava production regions, the roots are sold in local markets still attached to the base of the stem, a practice said to increase the storage life of the roots. Studies conducted at CIAT have shown that pruning the aerial portion of the plant before harvest reduces the level of physiological deterioration. When the interval between prunning and harvest was only one or two weeks, roots still attached to the stem base deteriorated less than unattached roots. But when the prunning-harvest interval was three weeks both types of roots were resistant to physiological deterioration. These changes were observed in roots from five cultivars, and the deteriora-

tion susceptiblity of roots from unpruned plants was unrelated to that of the pruned plants. Roots of cultivars MCol 1807 and MCol 22 (Fig.6) were the most susceptible before pruning, and the most resistant afterwards (Lozano *et al*, 1978). These results can be related to those of section (b), pruning acting as a severe and rapid defoliation.

Recently, it has been demonstrated that the effect of pruning is still observed with pruning-harvest intervals as long as 9 weeks, but the root starch content is reduced substantially, due to the utilization of these reserves to sustain plaint regrowth from the cut stump of the stem (Wheatley, 1982). Therefore, it is necessary to maintain the starch content after pruning, perhaps by chemical inhibition of regrowth. Associated with the loss of root starch, the texture and taste of the cooked roots is adversely affected, with the roots becoming hard and glassy after boiling, rather than softening. Pre-harvest pruning therefore reduces susceptibility of roots to post-harvest physiological deterioration but adversely affects root quality.


CONCLUSIONS


The recent investigations into post-harvest deterioration of cassava roots have lead to an increase in our knowledge of the causes of this enzymatic, physiological process, and the effects that pre-harvest environmental conditions can have on this. The next chapter will describe the theory and methods of cassava root storage, in which the basic knowledge outlined here is utilized to develop effective post-harvest storage technology.

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# STORAGE OF CASSAVA ROOTS FOR HUMAN CONSUMPTION


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## INTRODUCTION


In the previous chapter, the two types of post-harvest de-
terioration which affect cassava roots were defined, their cau-
ses explained and factors affecting their occurrance described.
Given the effect which these deteriorations have on the commer-
cial marketing of the fresh root, increasing margins and costs
and causing considerable losses to traders, retailers and consu-
mers alike (Janssen and Wheatley, 1985), the importance of de-
veloping a practical method of cassava root storage for periods
considerably longer than the 2 or 3 day current maximum, is evi-
dent. A storable cassava root would have considerable advant-
ages over a the persihable product: greatly reducing losses and
the risk of losses, thereby lowering marketing costs and also
providing a more convenient carbohydrate source for the consum-
er, one that can be stored rather than needing to be used imme-
diately.


## PRINCIPLES OF STORAGE


Theoretically, there are various principles which can be
utilized to eliminate or inhibit each of the two types of de-
terioration. Physiological deterioration requires oxygen for
its development and also involves enzymic reactions (Noon and
Booth, 1977; Rickard, 1982; Wheatley, 1982). Control of phy-
siological deterioration can be achieved, therefore, by elimi-
nating oxygen (or air) access to parenchymal tissues, or by in-
hibiting the enzymic reactions which produce the coloured pig-
ments. Storage in an atmosphere of nitrogen or carbon dioxide,
or in a vaccuum, total prevents deterioration through the eli-
mination of oxygen. Similarly, the use of an artificial barrier,
such as a thin layer of paraffin wax (Zapata and Riveras, 1976)
covering the root, has the same end result. Storage in low
temperatures ($<2°C$) is necessary in order to inhibit the enzy-
mic reactions, of polyphenoloxidase and peroxidase, which cata-

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lyse the formation of pigments.

The above mentioned storage systems all imply the use of specialised equipment or involve large capital expenditure (freezing, paraffin coating, controlled environment storage, etc). However, the current stage of the urban fresh market in Colombia, as in other Latin American countries, does not permit the use of such equipment due to cost and management factors (Janssen and Wheatley, 1985). It thus becomes necessary to develop a method both effective, simple to manage and of low cost for the use of farmers and traders currently engaged in cassava production and marketing and which will also serve the interest of retailers and consumers.

Physiological deterioration initiates close to regions of mechanical damage, where oxygen can most readily gain access to parenchymal root tissues. The root has, however, the capacity to form a new layer of suberised cells over camaged tissues (Booth, 1976). This "curing" process also occurs in other root and tuber crops (potato, yams, etc). It takes 4 to 5 days to cure a moderately sized damaged area of cassava root tissue if roots are stored under optimal conditions, which are: temperatures between 30-40°C and a relative humidity in excess of 85%. If curing is initiated immediately after harvest, physiological deterioration never starts to develop, and the roots are maintained in the fresh state.

Unfortunately, the conditions required to achieve rapid root curing (high temperature and humidity) are also favorable for the growth of fungal pathogens, thus subjecting roots to secondary or microbial deterioration. Growth of fungal and bacterial pathogens can be so rapid that microbially-induced rotting can occur before curing can seal off the damaged tissues. There are two useful practices which can limit this secondary deterioration: (a) lower the humidity sufficiently to slow microbial development, but not so low as to inhibit cruing. This balance is difficult to achieve in practice, or (b) root treatment with an antimicrobial agent before commencement of curing (Lozano *et al*, 1978; Wheatley and Orrego, 1985). Obviously, this treatment must be carried out using a chemical product which does not produce toxic residue problems in the root tissues destined for human consumption. The cassava root, having a thick peel layer (15-20% of root fresh weight) which is never eaten by human consumers, should be less vulnerable to this problem than some other root and tuber crops.

SIMPLE ROOT STORAGE PRACTICES

Field Clamps

Clamps or silos of straw and earth, similar to those often

674

used for potato storage, can be used to store cassava roots. 300-500 kg of roots, placed on a base of straw and covered with a further layer of straw followed by one of the soil, given a-dequate ventilation and a surrounding drainage ditch, have been used to store roots for over eight weeks (Booth, 1977).  Given adequate conditions, (internal temperatures <40°C and good ven-tilation) roots cure, with the formation of suberin over damaged tissues.  Root quality was similar to that of freshly harvested roots, although a slight decline in starch content and increase in sugars was noted.  The method is somewhat difficult to manage, especially where seasonal variations in climate cause differen-ces in ventilation and drainage requirements, and is useful only within the subsistance or rural marketing framework, since roots cannot be transported during storage.

## Storage in Boxes with Moist Sawdust Packing

Wooden or cardboard boxes can be used to store cassava roots, if the humid atmosphere required for curing is obtained by pack-ing roots in a matrix of moist sandust.  This system is simple and is currently used to export cassava from several Caribbean countries to the USA.  However, the high transport costs involv-ed in moving a heavy packing material and container, in addition to the roots themselves, precludes its use in internal fresh cassava markets.  75% of roots stored experimentally using this method were acceptable after four weeks, but a delay of one day between harvest and packing reduced this to 49% (Booth, 1977).

## Storage in Polyethylene Bags

Perhaps the simplest and most practical way of storing cas-sava roots through curing, is to pack them into polyethylene bags immediately after harvest (Oudit, 1977).  Once inside the sealed bags, the roots themselves generate the temperature and humidity required for curing to occur.  However, the rapid growth of fun-gal pathogens in these moist conditions makes a chemical treat-ment essential if secondary deterioration is to be avoided.  In CIAT a method of storing cassava based on fungicide treatment followed by packing into polyethylene bags has recently been de-veloped (CIAT, 1982, 1983, 1984; Wheatley and Orrego, 1985). This permits root storage without adverse quality changes and with minimal losses (<5%) for a two week post harvest period. This method is explained in detail in the following section.

METHODOLOGY OF CASSAVA ROOT STORAGE IN POLYETHYLENE BAGS

## Harvest and Selection of Roots

Roots are harvested in the usual manner, but with suffi-

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cient care to minimize mechanical damage. Roots to be stored
are selected, with all non-commercial roots (rotten, broken
and small sized) discarded and used for other markets or animal
or onfarm consumptionor drying. Curing cannot protect roots with
gross damage. Normally, >80% of harvested roots are suitable
for storage.


## Treatment

The fungicide recommended, both for the efficient control
of postharvest rotting and for its low toxicity to humans, is
Mertect (Ciba-Geigy, Colombia) whose active ingredient is thia-
bendazole. This product is in common use for the postharvest
treatment of potatoes and bananas, and is also approved for ve-
terinary use as an anti-helminthic compound. Analysis of cas-
sava roots treated with Mertect have demonstrated that residues
penetrating the parenchyma are less than 1 ppm after two weeks
of storage, and approved limits for potato are 5 ppm. Given
the thick peel layer of cassava the limited penetration of thia-
bendazole is understandable.

The product is sold as a suspension of 450g thiabendazole
per litre. The optimum concentration is 0.4% and roots are
treated by immersion for 5 minutes. The most practical way of
carrying out this treatment is to half fill a 55 gallon (200 L)
clean oil drum with 100 l of water, then add 400 ml of Mer-
keet to produce a 0.4% solution. After mixing well, the roots
can be treated, by immersing from 30 to 60 kg per lot, packed
into sisal sacks.

The same solution serves to treat 15 to 20 sackfulls (max-
imum 1200 kg roots). After treatment, the roots are emptied
onto a shaded area to dry for 15-30 minutes. If the are packed
into the bags immediately after treatment the humidity can be
exceesive; if allowed to dry out too much physiological deterio-
ration can initiate, especially if left in direct sunlight.

The site of the treatment operations must be close to the
field of cassava to be harvested, since a maximum time of three
hours between harvest and packing of roots is permisable; a long-
er time can lead to high losses caused by physiological deterio-
ration. In one experiment at CIAT losses after one week of stor-
age were increased from 0 to 30% when this time internal was in-
creased from 2-3 hours to 4-5 hours.


## Packing

On packing roots, another selection is made, eliminating
those which have suffered any damage during treatment, normally
very few. Experiments at CIAT have demonstrated that roots can
be packed in bags ranging from a capacity for 1 kg up to 20 kg

of roots, with the best results obtained from the small bag
sizes (1-5 kg roots).  Normally losses from small bag sizes
do not exceed 5%, and those from larger bags, 10% after a two
week storage period; the size can thus be chosen to meet market
requirements.  Neither bag color nor calibre affect the result,
although the large bag sizes must have sufficient strength to
resist the weight of the roots without tearing.

## Storage and Transport

     Roots must be stored in a place offering protection from
direct sunlight, rain and rodents.  In hot climates adequate
ventilation to stop the internal bag temperature from exceeding
40°C is necessary to prevent roots from rotting.  Roots must re-
main at least four days in an environment where curing can occur
rapidly, therefore immediate transport to cold climate areas is
not advised since both physiologicaland microbial rotting can
initiate from uncured areas of damage.  Once cured, roots can
be transported to any climate.

     Bags should be closed until sold to consumers, the quantity
per bag will thus depend on market requirements. ⊢Storage can
continue after purchase by consumers, so long as bags are re-
sealed, by string etc, after partial removal of contents to
maintain the correct conditions inside the bag.

## EVALUATION AND RESULTS OF STORAGE EXPERIMENTS

     Subjective evaluation scales for both types of deteriora-
tion have been designed, so that the level of losses can be e-
valuated and compared between experiments.  A visually assign-
ed scale of values from 0 to 5 is given to each individual root
for the following parameters:

          (i)    external growth of fungi and bacteria
          (ii)   internal microbial rotting
          (iii)  internal physiological deterioration

     Each parameter is evaluated according to the following
scale, considering only the root surface for the external eva-
luation (i), but considering root volume for the other two i.e.
a series of transverse cuts is made to assess (ii) and (iii).

     Based on these evaluations, a calculation of percentage
losses can be made, taking the mean of the evaluations for each
root and converting them to a percentage figure.  Losses due
to total deterioration can be calculated by summing the results
for microbial and physiological deterioration: this is the most
important parameter.  Normally 10 or 20 roots are evaluated per

treatment/bag; with small bag size a large number of replica-
tions must be used to obtain a representative number of roots.
It should be emphasized that these "loss" percentages do not
represent complete root loss, since some roots may be only
slightly affected, with the majority of the parenchyma in ex-
cellent condition.  Losses are generally concentrated at the
proximal or distal root extremes, which are often discarded
on food preparation.

| Scale | Symptoms |
|-------|----------|
| 0 | Absence |
| 0.5 | Trace: 1-5% of root affected |
| 1 | 5-20% "    "         " |
| 2 | 20-40% "    "        " |
| 3 | 40-60% "    "        " |
| 4 | 60-80% "    "        " |
| 5 | 80-100%     "        " |

     Using the above evaluation methodology, the overal results
of several storage experiments are presented in Table 1.  These
show that losses in hot to moderate environments are low, but
that in Popayán, a cold climate, high altitude site, losses were
considerable, demonstrating the importance of adequate curing
conditions.  However, when curing occurs rapidly and storage is
successful only traces of microbial growth are observed, almost
exclusively restricted to the two roots ends .  The level of
total deterioration is minimal.

     Thus, with adequate control of root mechanical damage and
efficient management of the operations here described, storage
times of two weeks or more can be achieved with minimal losses.

QUALITY EVALUATION OF STORED ROOTS

     Obviously, it is important that roots stored for one or
two weeks in an apparently satisfactory state are acceptable
to consumers as regards taste, texture and other quality para-
meters.  Storage experiments conducted at CIAT were routinely
analysed for changes in fresh weight, dry matter, starch and
sugar contents.  Tests were also made for changes in cooking
time, taste,texture, etc.  The results of a typical experiment
are shown in Table 3, where changes in quality were minimal.
Starch and dry matter content losses were not significant, in
general, and there was no change in the subjective eating qual-
ity.

TABLE 1.   THE RESULTS OF STORAGE EXPERIMENTS IN FOUR DIFFERENT EDAPHOCLIMATIC ZONES OF COLOMBIA.

| Site of experiment | Treatment | Storage time (weeks) | | | |
| | | 1 | | 2 | |
| | | microbial growth % | deterioration % | microbial growth % | deterioration % |
|---|---|---|---|---|---|
| CIAT | + Mertect | 2.2 | 1.4 | 7.2 | 4.6 |
| (Valle del Cauca | - Mertect | 22.5 | 2.1 | 24.2 | 7.7 |
| Sincelejo | + Mertect | 0.5 | 1.3 | 15.3 | 5.3 |
| (North Coast) | - Mertect | 14.8 | 7.8 | 33.5 | 23.5 |
| Carimagua | + Mertect | 0.7 | 2.6 | 7.0 | 0.0 |
| (Llanos Orientales) | - Mertect | 22.3 | 15.0 | 69.3 | 64.7 |
| Popayán | + Mertect | 7.0 | 30.0 | 14.3 | 36.0 |
| (Cauca) | - Mertect | 7.7 | 8.0 | 18.0 | 13.7 |

TABLE 2.   THE EFFECT OF BAG SIZE ON THE RESULT OF CASSAVA ROOT STORAGE

| Bag size (kg) | Treatment | Storage time (weeks) | | | |
| | | 1 | | 2 | |
| | | Microbial growth % | Total deterioration % | Microbial growth % | Total deterioration % |
|---|---|---|---|---|---|
| 20 | + Mertect | 6 | 2 | 16 | 4 |
| 20 | - Mertect | 70 | 8 | 86 | 36 |
| 5 | + Mertect | 2 | 2 | 14 | ? |
| 5 | - Mertect | 14 | 10 | 16 | 38 |

TABLE 3. QUALITY CHANGES IN ROOTS OF CMC 40 STORED IN 5 KG SIZED BAGS TREATED INTO MERTECT

| Storage time (weeks) | % Dry matter | % starch (dry wt basis) | % sugars (total) | Cooking time | Flavor | Texture |
|---|---|---|---|---|---|---|
| 0 | $36.46^{a\underline{1}/}$ | $89.8^a$ | $4.10^a$ | $35.5^a$ | good | soft |
| 1 | $36.53^a$ | $85.7^a$ | $5.17^a$ | $33.3^a$ | good | soft |
| 2 | $35.43^b$ | $84.7^a$ | $2.67^a$ | $38.4^a$ | good | soft |

[1]/ Significant differences from Duncan's multiple range test, shown by different letters (a,b) for each parameter

In addition, a large scale study of quality changes was made with a panel of 20 consumers, the results of which showed that stored roots were as acceptable as fresh ones of the same variety, although a slightly sweeter taste was noticed by some participants. This change was not necessarily adverse, however.

## POTENTIAL OF STORAGE TECHNOLOGY

The cost of Mertect treatment plus the polyethylene bag total US$0.02 per kg of roots. In Colombia, the marketing margin is sufficiently large, principally due to postharvest losses, and the risk of such losses, to cover the cost of this process. Table 4 shows the on-farm price compared to the consumer price in two Colombian regions in 1983. It is estimated (Janssen and Wheatley, 1985) that with the reduction in post harvest losses, the marketing margin will decrease from US$0.20-0.30 to US$0.13-0.18. This will leave room for a decrease in the consumer price and also an increase in the farm-gate price. Additionally, the greater convenience of the storable cassava root, and the increase in consumption which this should bring, should increase the demand and volumes traded.

TABLE 4. RELATION BETWEEN FARM LEVEL AND CONSUMER PRICES OF
FRESH CASSAVA IN TWO REGIONS OF COLOMBIA (1983)

| | Farm gate price $/Kg[1] | Consumer price $/Kg | Marketing margin $/Kg |
|---|---|---|---|
| Valle (Palmira) | 7 | 40 | 33 |
| North coast (Barranquilla) | 8 | 32 | 24 |

[1] Colombian pesos, 1983

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# CASSAVA ROOT PROCESSING FOR ANIMAL NUTRITION

Rupert Best*
Guillermo Gomez

## INTRODUCTION

Cassava world production totals 122 million tons of fresh roots (FAO, 1981), which represents a 16 percent increase compared to the estimated production in 1975. Cassava is produced in tropical regions of Africa, Asia and Latin America contributing to world production in 39, 36 and 25 percent, respectively.

Cassava roots are a major food staple for human nutrition and are used in various ways (cooked in water, baked, fied, etc.) or as pastes or flours ("gari" and "fufu" in Africa and "farinha" in Brazil and other Latin American countries). It is estimated (Phillips, 1974) that cassava roots contribute 39, 12 and 7 percent of the calorie requirements of the human population in Africa, Latin America and the Far East, respectively. While these figures can be somewhat different at present, they suggest, however, that cassava is more important as a food staple in Africa than in Asia and Latin America. In these latter regions other alternative uses of the roots are gaining increased importance.

Starch extraction, fuel alcohol production (especially in Brazil), and the feed market are the main alternative uses of cassava roots, specially in Latin America and Asia (Weber *et al*, 1978). The European Economic Community has increased its cassava importations, especially in the form of pelets or granules, from 2 million tons in 1975 to practically 6 million tons in 1978 (Anonymous, 1977; Thanh *et al*, 1979).

The balanced feed market in the European Economic Community is the most important consumer of cassava produced in Thailand and, to a lesser extent, in Indonesia. Balanced feeds in Europe include levels of cassava flour ranging between 15-35,

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15-25 and 10-12 percent of rations for swine, cattle and poultry, respectively; the most important total demand is from the swine sector (Anonymous, 1977).

The prospects of increasing the use of cassava roots in animal feeds in cassava producing countries, specially in Latin America, are most promising for the following reasons: the growing demand for broilers, and to a lesser extent of swine, observed in the last two decades; the production growth prospects of these sectors to meet the demand for their products; the resulting development of the balanced feed industry; the unsufficient production of cereal grains, especially sorghum, to supply the demand, which leads to continuous subsidized importations; and the possibility of reducing cassava production costs using improved technology that could place cassava at competitive prices for poultry and swine feeding (Pachico, 1980).

Poultry production is the most important market for balanced feeds in Latin America and in some regions of several countries, intensive or commercial swine production is gaining importance. To meet the demand in these markets, cassava roots should be processed to be dried, thus reducing their moisture content from approximately 65 percent to 14 percent, a level at which the dry product is stable and easy to handle.

THE CASSAVA DRYING PROCESS

The operations required to dry cassava chips are illustrated in Figure 1, including the additiona steps for grinding and pelleting the dry cassava.

The cassava roots harvested in the dry season and/or sandy soils have a low volume of soil adhered to their surface and generally they require no previous cleaning before being chopped. However, if the cassava roots are harvested during the rainy seasons and/or from humid soils, a large amount of soil is adhered to them, reducing the nutritional value of the dry product because of its high ash content, specially silica; under these conditions, it is necessary to clean the roots beofre chopping them and this operation can be done by submerging the roots in a waterwell or tank, or if possible, using pressure water spurts. It is not necessary to remove the husk nor the peel of the cassava roots for animal feeding.

In order to speed the drying rate and produce a high quality product, the root should be chopped into chips of uniform size to increase the surface area that will be exposed to the drying area. There are several cassava chipper models and the model to be selected will depend on the scale of operation of
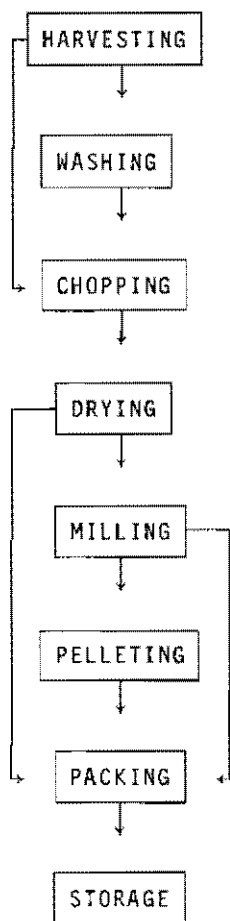
FIGURE 1.   FLOW CHART OF THE CASSAVA DRYING, MILLING AND PEL-
LETING PROCESS.

of the processing plant.

The cassava chip drying methods can be classified based on the technological level and cost, as follows:

1. Continuous artificial drying in rotary or conveyor dryers.

2. Batch drying in static bed dryers using forced air, and

3. Natural drying on cement floors or trays.

The selection of one of these methods will depend mostly on the amount of cassava to be dried, the availability of capital and labor cost, as well as the availability of relatively cheap energy sources. In the following section a more detailed description will be given of the drying methods.

Once the chips are dried, there are three alternative handling methods:

1. Packing the chips for storage

2. Grinding the cassava chips in a hammer grinder in order to increase the product's density and thus reduce transportation costs.

3. In the case of processing plants located far away from the consumption centers, it is advisable to consider pelleting the product thus increasing its density even more and easing its handling.

Dry cassava chips and pellets are packed in jute or polyethilene bags, while cassava flour requires cotton or multilaminar sacks. If the chips have to be stored for a long time, it is advisable to monitor moisture absorption and mold development. Besides, the necessary precautions should be taken to avoid damages caused by rodents and insects, while considering the danger that poisons and insecticides with residual effects represent.

The quality standards for pellets, dry chips and cassava flour, are based on their starch, moisture, fiber, ash and cyanide contents. The specifications for good quality dry cassava products are the following:

| | |
|---|---|
| Starch (minimum) | 62% |
| Crude fiber (maximum) | 5% |
| Ashes or sand (maximum) | 3% |
| Moisture (maximum) | 14% |
| Hydrocyanic acid (maximum) | 100ppm |

DRYING METHODS

## Continuous artificial drying

There are two main types of artificial appropriate for cassava: rotary dryers and conveyor dryers. In the rotary dryer, the humid product rotates within a cylindrical chamber through which hot air circulates while the product is continuously mixed. The steel cylindrical chamber is mounted on rollers with a slight inclination. The interior surface of the chamber is provided with agitating blades that mix the product as the chamber rotates, forcing the product to fall through the hot air flow. The humid product is continuously introduced through the upper most end of the cylin der and the dry product is removed through a spillway located in the lowest extreme of the cylinder. The air can flow either in the same direction or contrary to the direction in which the solids move. Because of the mixing process, high evaporation speeds are obtained as well as a uniform drying. The conveyor dryer consists of a tunnel that can be up to 24 m long. The humid product is transported throughout the system on a belt conveyor and the air can flow either in the same direction or contrary to the direction in which the product moves. The most frequently used system is the vertical flow in which the air flows across the belt conveyor and the product layer. High drying speeds are obtained since the area exposed to the drying air is relatively large and the contact between air and product is close.

Some cassava dryer manufacturers are the following:

Rotary Dryers

Adolph Hubrich
Maschinenbau
2000 Hamburg 1
Kirchenallee 25
West Germany
Telephone: 249992

Buell Limited
George Street Parade
Birmingham B3 1AA
England
Telephone: 021 236 5391
Telex: 338958

Conveyor Dryers

APV Mitchell (Dryers) Ltd.
Danton Holme
Carlisle C A2 5DU
England
Telephone: 34433
Telex: 64139

.Industrias Maquina D'Andrea S/A
Rua General Jardim 645
01223 Sao Paulo
Brazil
Telephone: 255-6177
Telex: 1124499 CAMB BR

## Batch Drying in Static Bed Dryers

This drying method basically consists of a uniform airflow moving across a 100 to 300 mm product layer. The dryer is a simple chamber built with bricks or wood, with a false perforated plate floor on which the product is placed. To obtain an uniform drying, the product should be raked or turned. The main disadvantage of this type of dryer is the long drying period, although it is the most common method used at the farm level to dry grains and some forages. Due to the high initial moisture content of certain crops such as cassava, the user can take the maximum advantage of the drying capacity of the air, by using a system in which the air flow is reversible; that is, the hot air first moves through a chamber and then through the second one. The air flow direction is inverted when the first chamber is unloaded and reloaded so that the second one receives the dry air and finishes drying. The development of the drying method in static beds for agricultural products has occurred mainly in the Centro Nacional de Treinamento en Armazenagem, Brazil (Sinicio and Roa, 1980) and at present, the method for cassava is being refined at CIAT.

## Natural Drying on Cement Floor and Trays

Cassava chips dried on cement floors are uniformally distributed on the surface by using a wooden rake as the one illustrated in Figure 2. To obtain a uniform drying, the chips are raked at two-hour intervals or less by using the rake that appears in Figure 3. At night or before it rains, cassava chips are collected with wooden shovels (Figure 4) and covered with plastic or canvas. The use of inclined trays allows accelerating the drying period, since the airflow circulates through the chips. The trays are built in a wooden frame and their base made in 1"-mesh and a fine plastic mesh (Figure 5). The trays at an angle of 25 and 30° on two rows of bamboo posts and rails in order to take maximum advantage of wind direction (Figure 6). Before it rains, the trays are pilled horizontally one on top of the other, and the top tray is covered with canvas or with a corrugated iron sheet (Figure 7). The lower tray is placed on two bamboo posts that holds it above the soil surface. An advantage of tray drying over floor drying is the possibility of using the night hours to initiate drying in non-rainy seasons.
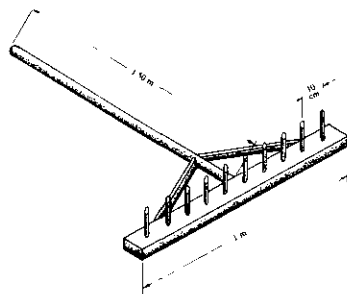
FIGURE 2. WOODEN RAKE TO DISTRIBUTE CASSAVA CHIPS ON THE CONCRETE FLOOR.
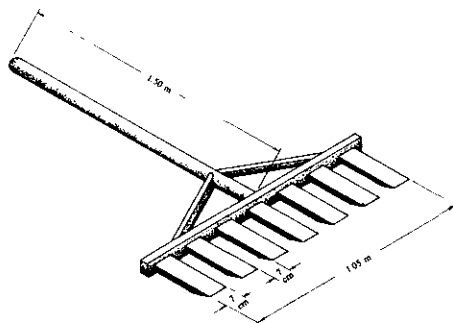


FIGURE 3. WOODEN RAKE TO TURN CASSAVA CHIPS ON THE CONCRETE FLOOR.
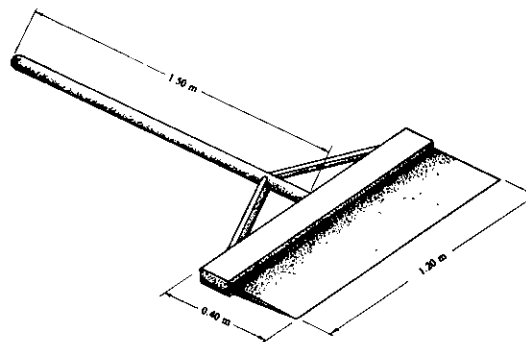


FIGURE 4. WOODEN SHOVEL TO COLLECT CASSAVA CHIPS.
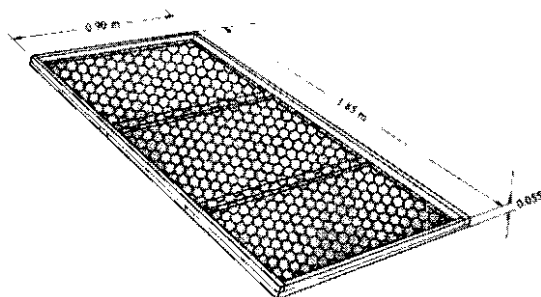
FIGURE 5.  TRAY WITH A WOODEN FRAME AND WITH 1"-MESH AND A PLASTIC SCREEN
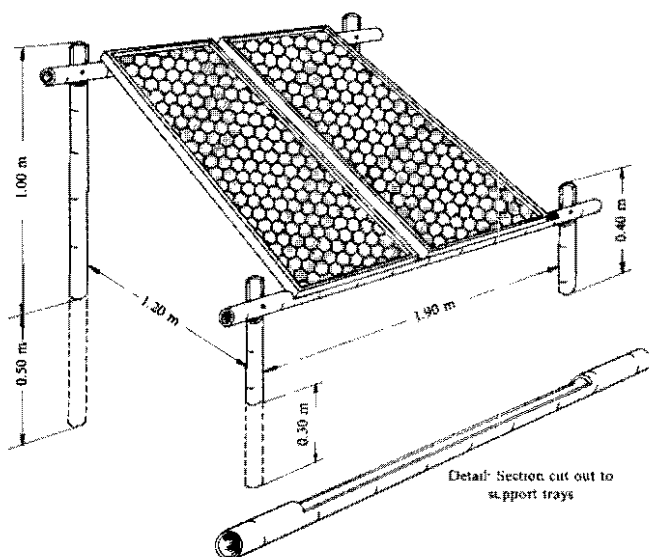


FIGURE 6.  BAMBOO FRAME THAT SUPPORTS THE DRYING TRAYS
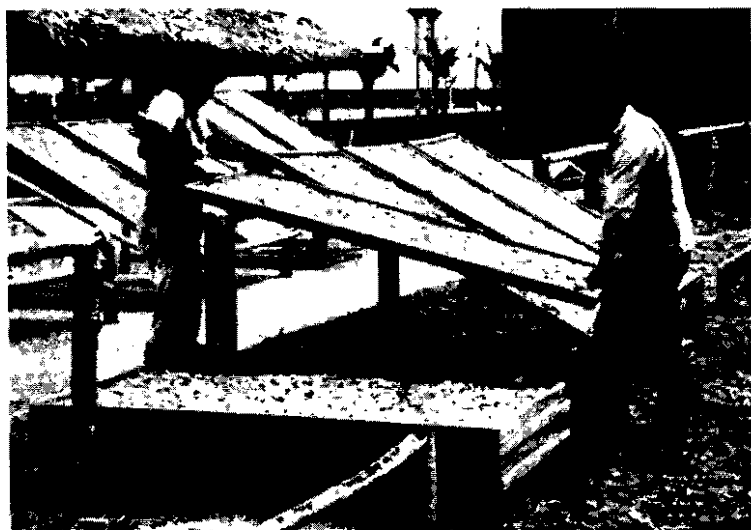
FIGURE 7.   INCLINED DRYING TRAYS WITH A MESH BASE AND THAT CAN BE
            PILED AT NIGHT OR BEFORE IT RAINS.

DRYING THEORY


This section presents some considerations on the theoretical aspects of drying agricultural products using hot air, with emphasis in cassava chip drying.


Terminology

1. Moisture content.- The moisture content of a product is expressed based on a weight; that is, water mass per unit mass of wet product.

Equation A

$$C = \frac{Ma}{Ma + Ms} \times 100$$

where,

C = moisture content, %
Ma = water mass, g
Ms = Dry solid components, g
Ma + Ms = Total mass of the product, g.


By using equation A, the following variables can be estimated:

a. The moisture content of fresh cassava.

Example: a fresh cassava sample weighing 110 g is oven-dried until the weight is maintained constant at 36 g (that is, all the water is eliminated, leaving only the solid components. What was the moisture content of fresh cassava?

In equation A, Ms = 36 g and Ma = 110 - 36 = 74 g.


$$C = \frac{74}{74 + 36} \times 100$$

$$= 67.3\%$$


b. The cassava yield, to be dried at a given moisture content.

Example: fresh roots of a cassava variety have a 65% mois-

ture content. How much will 1000 Kg of these roots weight when dried at 14% moisture?

The calculation has to be done in two steps:

Step 1. First calculate the weight of the dry solid components in the original amount. In equation A, C = 65% and Ma+Ms = 1000 Kg.

$$Ma = \frac{(Ma + Ms)\ (C)}{100} = \frac{1000}{100} \times 65$$

$$Ma = 659\ Kg$$

$$and \quad Ms = 100 - 650$$

$$Ms = 350\ Kg$$

Step 2. Substitute again in equation A to determine the new water mass in the dry cassava, where C = 14% and Ms = 350.

$$C = \frac{Ma}{Ma + Ms} \times 100$$

$$14 = \frac{Ma}{Ma + 350} \times 100$$

$$14(Ma + 350) = 100\ Ma$$

$$Ma(100 - 14) = 14 \times 350$$

$$Ma = 57\ Kg$$

The the final weight of the dry cassava, with a 14% moisture content, will be 407 Kg.

2. Equilibrium moisture content.- In general, when an organic product is maintained in contact with air at constant temperature and humidity, until equilibrium is reached, the product reaches a given moisture content. This moisture content is known as equilibrium moisture content under the specific condi-

tions. It is possible to measure the equilibrium moisture content under the specified conditions. It is possible to measure the equilibrium moisture content of a product under different temperature and humidity conditions and thus elaborate curves that will relate the moisture content of the product and the atmospheric humidity, with that in equilibrium, at different temperatures. These graphs are called sorption isoterms and Figure 8 shows typical curves for cassava. It is very important to learn about the sorption characteristics of the products that are going to be dried, since the equilibrium moisture content is the lowest moisture content that can be reached under given temperature and humidity conditions. In studying the stability of stored dry products, it is also important to understand sorption performance.

## Factors that Affect Cassava Drying

The factors that can affect cassava drying time are: chip geometry (shape and size), chip load per unit area, air speed, temperature and humidity, as well as dry matter content of the fresh chips. In artificial heat dryers all of these parameters can be optimized to minimize the drying time and guarantee a high quality product. In natural drying methods, in which the heat source is solar radiation, air speed, temperature and humidity depend on the environmental conditions, and very little control can be exerted over them. Each of these parameters will be discussed in more detail now.

1. Chip geometry.- Water elimination from the cassava chips is produced when water moves from the inside of the solid to the surface where it evaporates in the main flow of the drying air. Therefore, drying speed depends on the total surface area of the chips and the speed at which the saturated area is eliminated. Drying time can be reduced by chopping the roots so as to obtain regular shaped chips with a size that will allow to maintain a structural uniformity and free air circulation between chips.

Most of the research conducted on cassava chip geometry is related to natural drying on cement floors or trays. According to Roa and Cock (1973) natural drying is optimized when cassava chips are rectangular in shape and with a size of 8 x 8 x 50 mm. On the other hand, Thanh *et al* (1978) dried cassava chips of different shapes (circular, rectangular blocks, cubes, strips or splinters and slices) and sizes (1-5 mm thick, 10-80 mm long and 5-25 mm wide) on concrete floors or on trays and concluded that both shape and size affect significantly the drying period. Ospina and Vasconcellos (1980) compared three different geometrical shapes (rectangular bars 10 x 10 x 50 mm, slices 10 mm thick and cubes 10 x 10 x 10 mm), in drying trials using a static bed

696
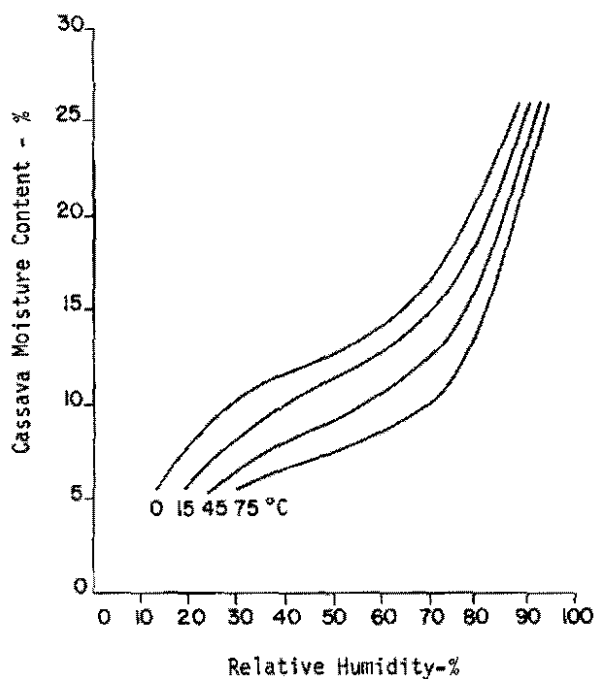
FIGURE 8. SORPTION ISOTERMS OF CASSAVA (Roa, 1974).

dryer with 100 mm layers, and found that cube-shaped cassava chips had the highest drying efficiency.

There are two types of chippers used mostly in Malaysia and Thailand. Both models have a similar basic structure and the difference between both is in the rotary disc; the Malaysia type chipper requires a minimum of 24 interchangeable corrugated blades mounted on a 10 mm thick disc (Figure 9); in the Thailand type chipper, the 2 mm-thick iron rotary disc is perforated with six rows of 25 mm-diameter holes, with cutting edges, which allow obtaining 4-6 mm thick cassava chips (Figure 10). Best (1979) and Thanh *et al* (1979) have described these two models technically. Another type of chipper that produces rectangular bars of 10 mm$^2$ sections is being developed in Brazil (Sinicio and Roa, 1980).

2. Chip load per unit area.- The load of cassava chips per unit area, measured in kilograms of fresh product per square meter (Kg/m$^2$), is a function of the airflow through the chip layer. Chip load for natural drying on cement floor is restricted due to the reduced airflow at the soil level, and depending on the climatic conditions, the optimum load appears to be between 5-10 Kg/m$^2$. On the other hand, if inclined trays are used, the chip load can increase according to wind speed, as can be observed in the following information:

| Wind characteristics | | Load in trays (Kg/m$^2$) |
| --- | --- | --- |
| Conditions | Speed (m/seg) | |
| Light wind | Up to 1 | 10 |
| Constant breeze | 1-2 | 10-13 |
| Constant wind | More than 2 | 13-16 |

In static bed dryers, in which the drying of the chip layer progresses from the lower sections to the upper sections in the direction of the airflow, layer depth appears to be controlled by the deterioration rate occurring in the upper chip layers. In practice, layer thickness has not been higher than 300 mm, which is equivalent to an approximate load of 165 Kg/m$^2$, by using airflows that range between 43 and 103 m$^3$/min/ton of fresh

FIGURE 9.  MALAYSIA-TYPE CASSAVA CHIPPER (A) AND A DETAIL OF THE INTER-
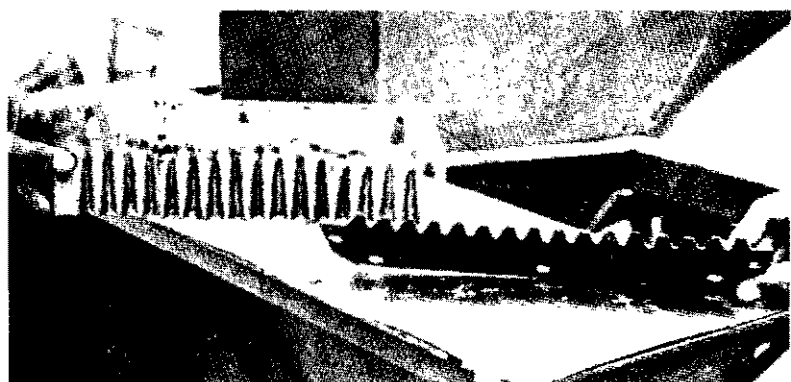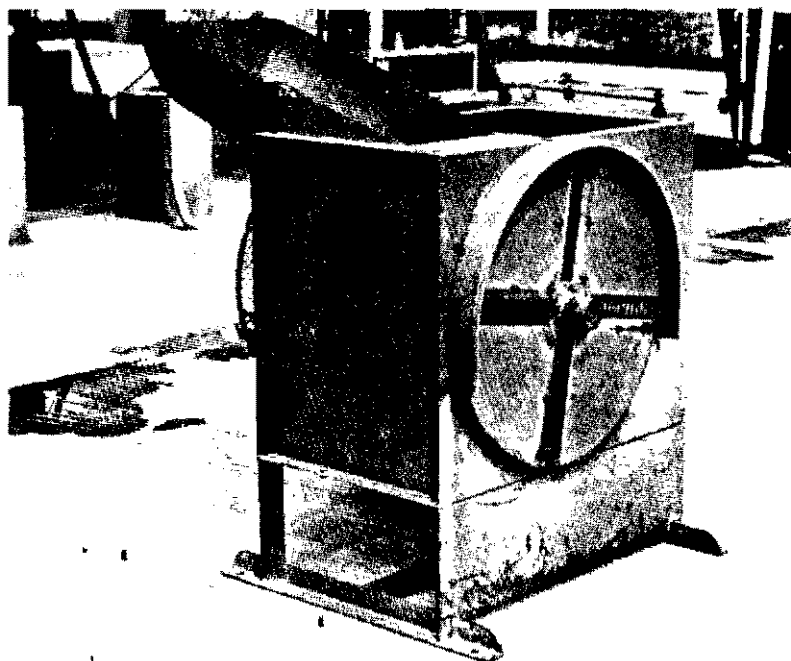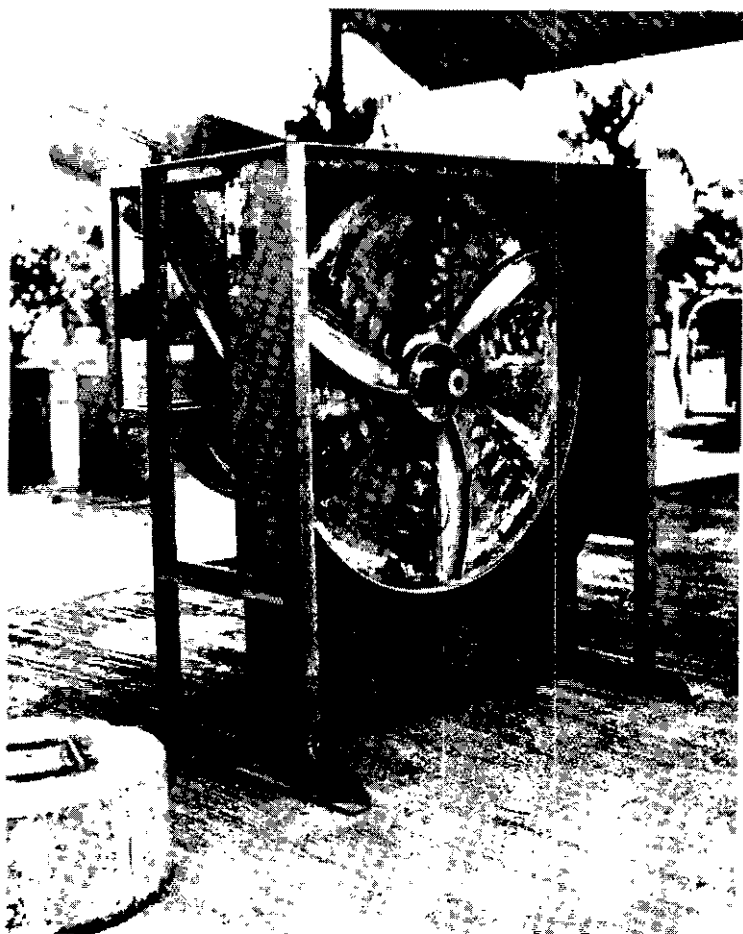CHANGEABLE BLADES (B).

FIGURE 10.    THAILAND-TYPE CASSAVA CHIPPER.

cassava, depending on temperature and relative humidity (Ospina, 1980).

    3. Air speed, temperature and humidity.- The drying characteristics of cassava chips using artificial heat have been studied using different temperatures (55, 66 and 77°), air speeds (31, 61 and 84 m/min) and variable thicknesses (50, 80 and 100 mm) of the cassava chip layers (Webb and Gill, 1974). It was found that the drying process with artificial heat was of diffusive nature, with a rapid initial stage of drying, but with a second slower drying stage towards the end.  In this second stage, the internal resistance to water movement controlled drying speed more than external factors.  On the other hand, Chirife and Cachero (1970) using different chip layer depths (20-120 mm), air speeds (2300-5200 Kg/h-m$^2$) and air temperature (55-100°C) concluded that with layers of up to 120 mm, the drying period is not reduced at air speeds higher than 4500 Kg/h-m$^2$.  Additionally they found that the product is roasted at temperatures higher than 84°C.

    In natural drying systems, climate is a phenomenon over which very little control can be exerted.  However, the drying process can be improved if careful observations are made of the variations in temperature and relative humidity, wind speed and solar radiation.  As mentioned above, the drying process of cassava occurs in two stages and in the ease of natural drying, this means the following:

    a. During the first stage when the fresh chips lose moisture rapidly, air circulation as wind is more important than air temperature and humidity.  If wind speed is sufficient, this stage can be completed during cloudy days or even at night. Therefore, during low rainfall seasons, cassava can lose a considerable amount of moisture if it is left all night in the trays over the supports.  Figure 11 shows a typical drying curve for inclined trays, based on a trial in which drying commenced at 5 p.m. and continued during the night.  Table 1 illustrates the effect of wind speed at five different sites on the amount of water eliminated from the cassava chips and demonstrates that the higher the wind velocity the quicker the drying process. For comparison purposes, fresh cassava chips left on cement floors over night only lose a small amount of moisture because of the low wind speed at the soil level and the fact that they can not be raked at the required frecuency.

    b. During the second drying stage, when moisture content has reached approximately 30%, water elimination is slower and a high temperature is required to complete the drying process. During this stage, air relative humidity should be less than 65% in order that the moisture content of cassava can reach an appropriate level for storage (see Figure 8).  In some cases,

701
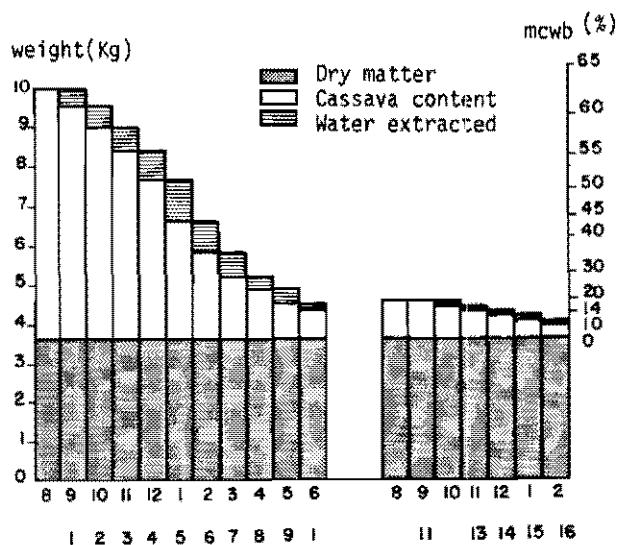
FIGURE 11. TYPICAL DRYING CURVE OF CASSAVA CHIPS IN TRAYS; MOISTURE LOSS IN RELATION TO HOUR OF THE DAY.

TABLE 1.   LOSS OF MOISTURE BETWEEN 5 P.M. AND 8 A.M. AT 5 SITES WITH DIFFERENT
CLIMATIC CONDITIONS[a].

| Parameter | Site | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| CLIMATIC CONDITIONS[b] | | | | | |
| Temperature, °C | 19 | 20 | 22 | 27 | 27 |
| Relative humidity, % | 87 | 87 | 79 | 71 | 84 |
| Wind speed, m/seg | .30 | .45 | .87 | .35 | .15 |
| CASSAVA MOISTURE CONTENT | | | | | |
| At 5 p.m., % | 59 | 60 | 63 | 61 | 64 |
| At 8 a.m., % | 58 | 57 | 47 | 50 | 61 |
| Water loss during the night, % | 7 | 11 | 48 | 34 | 10 |

a   The drying was carried out in inclined trays with 10 Kg of fresh cassava per
m$^2$.

b   Mean of the climatic conditions between 5 p.m. and 8 a.m.

specially during the rainy season, relative humidity remains
over 65% and the drying process will continue until the weather
improves. To accelerate drying on cement floors, specially dur-
ing the second stage, the feasibility of using black painted
floors or mixing black pigment (Bayer powder or lampblack) with
cement at a rate of 1:5 when the drying platform is being forged,
has been studied. The increase in solar radiation absorption
causes surface temperatures to increase in approximately 6°C
(Thahn *et al*, 1978). However, the efficiency of the black-co-
lored floor is linked to the load of cassava chips per unit area;
the difference between the black floor and the normal concrete
floor, is reduced and eliminated at loads of 10 Kg/m$^2$; therefore,
the additional cost of painting or building black coloured floors
is not justified.

A set of trials was established at several sites in order
to determine drying time under different climatic conditions.
The results are presented in Table 2 and indicate the following:

a. Drying almost always takes more than 10 hours but less
than 20. Cassava will dry in less than one day only under ex-
ceptional environmental conditions. However, in sites where
wind speed and solar radiation are low, drying can take longer
(up to 3 days as occurred occasionally in site 2).

b. Almost the same number of hours is required to dry dou-
ble the amount of chips per m$^2$ in trays compared to the use of
cement floors.

c. In very humid areas (sites 1, 2 and 5), cassava drys
more rapidly if wind speed is high.

4. Initial dry matter content of cassava.- The dry matter
content of fresh cassava is affected by several factors such as
the variety, harvesting age and the edaphoclimatic conditions,
but in general, it ranges between 30 and 40%. This variation
represents 30% of the difference in the amount of fresh cassava
required to produce a ton of dry cassava (Table 3).

The selection of varieties with high dry matter content is
therefore important because of the following reasons: less dry-
ing time, lower labor requirements per ton of dry cassava and,
in the case of aritificial drying, fuel costs are reduced. In
the drying process used in the Compañia Brasilera Máquina D'An-
drea a compression operation of the cassava chips has been in-
corporated before placing the product in the dryer, thus elimi-
nating 25-30% of the water (Vitti, 1966). An attempt has been
made to adopt this practice in natural drying (Best, 1978) by
using a manual press with a capacity of 70 Kg per batch. Water
elimination was satisfactory but drying was not accelerating
since the water extracted with the press is the same that is

TABLE 2. EFFECT OF THE CLIMATIC CONDITIONS IN 5 SITES ON THE DRYING TIME OF CASSAVA CHIPS IN TRAYS AND CEMENT FLOORS[a].

| Parameter | Site | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| CLIMATIC CONDITIONS | | | | | |
| Temperature °C | 24 | 26 | 26 | 30 | 31 |
| Relative humidity, % | 70 | 67 | 66 | 64 | 68 |
| Wind speed, m/seg | 1.9 | .8 | 1.2 | .9 | 1.0 |
| Solar radiation, $cal/cm^2/seg$ | .73 | .58 | .61 | .65 | .71 |
| DRYING HOURS[b] | | | | | |
| On trays at 10 $Kg/m^2$ | 12 | 19 | 13 | 12 | 13 |
| On black cement floor at 5 $Kg/m^2$ | 11 | 17 | 15 | 10 | 13 |

a   The drying trials were conducted between 8 a.m. and 6 p.m.

b   The drying trials were initiated at 8 a.m. and the cassava was covered all night from 6 p.m. Therefore, each drying day lasted 10 hours. For example a 17-hour drying period means one day of 10 hours plus 7 hours the next day.

TABLE 3.  VARIATIONS IN CASSAVA YIELDS WITH DIFFERENT DRY MATTER CONTENTS

| Fresh cassava dry matter content % | Amount of fresh cassava required to produce 1 t of dry cassava with 10% moisture content ton | Yield % |
|---|---|---|
| 30 | 3.0 | 33.3 |
| 35 | 2.6 | 38.5 |
| 40 | 2.3 | 43.5 |

eliminated rapidly in the natural dying process.

## REQUIREMENTS FOR THE ESTABLISHMENT OF A PROCESSING PLANT

There are several factors that should be considered to establish and operate a processing plant to dry cassava root chips. Several attempts have been made in several Latin American countries and most of them have failed or are not operating at the projected production scale. One of the main reasons of these failures has been the lack of integration of the production and processing stages and the scarse information on economic feasibility studies. Considering that most of the cassava production is used for fresh consumption, it is very difficult to compete with this market, unless production is increased considerably and production costs reduced so that the price of the raw material is competitive to add the processing cost and obtain a final product that will be profitable when placed at the market.

In addition to production cost data, studies on potential markets to use processed products are of vital importance. Cassava producing areas are frequently located far from the poultry or swine production centers and transportation cost become most important.

Although the list of factors that should be taken into account is quite large, those that appear to be more relevant and important are:

- Availability of raw material
- Quantity requirements
- Quality requirements
- Infrastructure
- Marketing
- Production costs

Cassava processing economics is affected mainly by two competitive situations (Edwards, 1974):

Cassava supply

a. The processing plant should be competitive with other cassava uses, especially with subsistence agriculture, a situation in which the fresh market is the most important one.

b. Cassava production competes with other crops for the use of land.

707

## The Demand of the Processed Product

The existence of the market in which the product will be used.

Regarding cassava root supply and availability, two aspects should be considered, although one of them depends largely on the other: (1) the price that has to be paid to obtain the roots and, (2) supply continuity.

Since the area planted to cassava is frequently programmed to meet fresh consumption demand, a surplus of the supply is necessary to meet the demand of such market and the able to process the rest.

Apparently there are two ways to meet a regular supply of cassava roots:

1. By creating cooperative organizations among small and intermediate farmers with technical assistance and credit facilities from official agencies and,

2. By establishing large plantations in large-scale enterprises that will process all the roots that they themselves produce.

Good roads in the production area are required to justify the investment in an agroindustry of this nature. Most of the success of the industry in Thailand is due to the excellent roads in the cassava producing areas. Roads and transportation facilities are essential.

The main market for the processed product will be the feed processing plants, especially for poultry and swine. Since the majority of cassava producing countries in Latin America are cereal grain importers to meet the demand for animal feeds, there is no doubt of the existence of a potential market for dry cassava chips or cassava meal. The main factor is the relative price that can be paid for the product, which is generally between 80-85% of the price for sorghum.

The price of the processed product will depend on a set of factors inherent to processing, but mainly on the price of the raw material. For example, in Thailand 56% of the price of the cassava pellets placed in Rotterdam (the Netherlands) corresponds to the price paid to the farmer (Anonynous, 1977). Edwards (1974) describes detailed economic analyses with cost models for the production of cassava dry chips and pellets.

# CONCLUSIONS - THE COLOMBIAN CASE

The cassava chip drying process for their use in animal feeds should be economically feasible and profitable for it to become an important line for cassava producers. To ensure some success, it is necessary to consider integrating cassava production and processing.

The characteristics of the cassava production regions in latin America allow to predict that in most cases, associations, cooperatives and other types of associations can be responsible for disseminating the cassava drying process for animal feeds. Under these conditions, the most appropriate drying method is the natural drying system, since it can be easily handle by the farmers themselves, requires low capital investments and allows creating working opportunities, especially during seasons of the year in which agricultural activities are restricted because of low rainfall.

The experience gained in the northern coast of Colombia suggests that while the process is simple, it is necessary to establish pilot plants for demonstrations purposes, preferably with the cassava producers themselves, to show the actual feasibility of the process and be able to gather basic information on production and processing costs. The possibility in increasing cassava productivity is of key importance to obtain roots at a lower price thus allowing the processing plant to obtain a profit margin.

It is probable that in most of the cassava producing areas the establishment of several small-scale processing plants is more convenient than a few large-scale operations. Increasing the size of the processing plants would certainly force mechanization of the different operation stages and, therefore, this will increase the processing costs.

Results obtained in the northern coast indicate that a plant with a drying area of 500-1000 $m^2$ can be easily handled by an association of 20 farmers. In a 4-month period, which corresponds to the dry season of the year, a 500 $m^2$ plant would process approximately 60 tons of fresh cassava per month (loads of 10 Kg/$m^2$ and 2 days per batch, 3 batches per week) or 240 tons in 4 months. With a 38% yield, approximately 90 tons of dry chips can be processed.

Table 4 shows the investment required in facilities, equipment and tools to establish a plant of this size. On the other hand, Table 5 shows the production costs of 1 ton of dry cassava (first semester 1982). As can be observed, the cost of raw material represents approximately 83% of the total production cost. The profit ($1175 per ton of dry cassava) could be incr-

TABLE 4. INVESTMENT REQUIRED TO ESTABLISH A DRYING PLANT WITH 500 m$^2$ OF CONCRETE FLOOR IN COLOMBIAN PESOS[1]

| Item | Unit value $ | Partial value $ | Total value $ |
|---|---|---|---|
| a. FACILITIES | | | 289,500 |
| Drying patio, 500 m$^2$ | 500/m$^2$ | 250,000 | |
| Storage warehouse, 50 m$^3$ | 500/m$^3$ | 25,000 | |
| Wire screen fence, 90 m | 50/m$^3$ | 4,500 | |
| Shed for chipper | --- | 10,000 | |
| b. EQUIPMENT | | | 95,000 |
| Chipper | | 60,000 | |
| Gasoline motor 3 hp. | | 20,000 | |
| Scale, 500 Kg capacity | | 15,000 | |
| c. TOOLS | | | |
| 2 wagons | 2,500 | 5,000 | |
| 4 shovels | 250 | 1,000 | |
| 4 rakes | 100 | 400 | |
| 4 collectors | 200 | 800 | |
| 250 packing sacks | 40 | 10,000 | |
| 1 plastic tent | 50/m$^2$ | 12,500 | |
| Subtotal investment | | | 414,200 |
| Incidental expenses, 5% | | | 20,700 |
| TOTAL | | | 434,900 |

[1] US$1.00 = Col$60.00, January, 1982

TABLE 5.  PRODUCTION COSTS AND SALES PRICE OF 1 TON DRY CASSAVA COLOMBIAN PESOS[1]

| Item | Cost $ |
|------|--------|
| Raw materia, 2600 Kg at $3.70/Kg | 9620 |
| Labor 2.5 wages at $250/wage | 625 |
| Fuel, transportation and others | 1380 |
| TOTAL | 11625 |
| Sales price of dry cassava placed in the feed processing plant $12.80/Kg | 12800 |
| Profit per ton of dry cassava | 1175 |

1 US$1.00 = Col$60.00, January 1982.

eased considerably by reducing the purchasing price of the raw
material. To do this, it will be necessary to increase the pro-
ductivity of the cassava crop.

One of the factors limiting natural drying is the limited
dry time due to the climatic conditions. The feasibility of
extending the operation time is being studied by refining the
drying method in static beds and incorporating an air heating
system. Depending on the region where the drying plant will be
established, there are several systems that can offer feasible
alternatives such as solar radiation storage through solar col-
lectors and the burning of wood, coal or agricultural residues.

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714

# UTILIZATION OF CASSAVA ROOTS AND PRODUCTS IN ANIMAL

# FEEDING

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Jorge Santos N.
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## INTRODUCTION

Among the root and tuber crops, cassava is the most important species in tropical regions and is a significant calorie source for the population of these areas. Approximately 60% of the cassava production in Latin America is used for human consumption and the remaining 40% is employed for stach production, animal feeding and fuel alcohol production, especially in Brazil (Pachico and Lynam, 1981).

While most of the cassava roots are used in human nutrition, the prospects of their use in animal feeding have increased considerably in the last years. Agricultural policies in the European Economic Community have demonstrated from Thailand to substitute cereal grains in feeding programs for swine, poultry and cattle (Coursey and Halliday, 1974; Phillips, 1974).

In many tropical regions of the world, and specially in Latin America, animal production as a whole and poultry in particular have increased notoriously during the last 2 decades. Therefore, the demand for balance feed has increased to meet this continuous development. Unfortunately the production of cereal grains normally used in animal feeding (sorghum and maize) in tropical regions has shown a lower growth rate than the demand, forcing a growing importation of these inputs.

On the other hand, as a result of research in genetic selection and development of efficient cropping methods and cultural practices, it appears relatively easy to increase cassava yield and productivity under field conditions, as evidenced by

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the results of regional trials and technology validation trials
at the farm level. Consequently, the use of cassava for alter-
native markets such as that of animal feeding would be economic-
ally feasible.

The objective of this paper is to review the information
related to the nutritional quality of cassava roots and leaves
and to the utilization of these products in feeding programs
for domestic animals, specially poultry and swine.

## CHEMICAL COMPOSITION OF CASSAVA ROOTS AND PRODUCTS

Cassava roots contain 60-65% water and 35-40% dry matter,
because of its high moisture content, roots deteriorate rapid-
ly after harvest and should be processed (ensiled or dried) to
preserve them for a longer period of time.

For use in human nutrition, the roots are peeled, the peels
are eliminated and the pulp (parenchyma) is subject to some ther-
mic process before being consumed. For use in animal feeding,
whole roots, including the peel, are chopped into chips or
splinters that can be fed as fresh chips, especially to pigs
and cattle, or can be subject to a drying process to transform
them into dry chips and then cassava meal, or can be ensiled to
preserve them for longer periods of time.

Table 1 shows the chemical composition of fresh, ensiled
or dry meal cassava chips, leaves and dry forage, as well as
the composition of sorghum and alfalfa hay. In general, fresh
or processed cassava root chips are characterized by their low
protein, ether extract (fat) crude fiber and ash contents, but
possess high levels of nitrogen free extract or soluble carbo-
hydrates composed mainly by starch and a small amount of sugars.
Therefore, cassava roots and their by-products supply mainly
calories as high quality, highly digestible starch.

A comparison between the composition of cassava roots and
its by-products and sorghum clearly shows that cassava by-pro-
ducts are defficient mainly in protein. Therefore, if sorghum
(or maize) is to be substituted by cassava root products, these
will have to be supplemented with additional protein ingredients
such as fish meal, soybean meal, cotton seed meal and others.

The best way to preserve cassava roots for their use in
animal feeding is to process them through a chipper to obtain
chips, pieces or splinters, that are then sun-dried and turned
into a stable product with 10-14% moisture. Dry chips can be
stored as such or pelletized or ground into meal. Dry ground
cassava for meal is the product employed as ingredient to pre-
pare balanced feeds for domestic animals. The drying process

allows concentrating the nutrients present in fresh cassava roots (Table 1), specially starch, and at the same time, it is one of the most efficient methods to eliminate the cyanide present in cassava.

Sun-dried cassava leaves and foliage (leaves and tender stems) or with artificial heat, are protein feeds with a chemical composition similar or superior to that of sun-dried alfalfa hay (Table 1). Additionally, some cassava varieties can be planted at higher densities (number of plants per hectare) at smaller distances to produce forage that can be used especially for rumiant feeding. Cassava foliage (leaves and tender stems) generally contains more protein than forage cassava. The potential utilization of cassava leaves and foliage as well as forage cassava production are promising research areas to achieve the integrated utilization of the crop.

## CYANIDE CONTENT OF CASSAVA ROOTS AND PRODUCTS

In the literature review on the use of cassava in animal feeding, some data on poor results compared to those obtained with cereal grains are reported, and frequently it is concluded that when these poor yields are obtained, these can be due to the presence of hydrocyanic acid in cassava products. In most cases, however, not even the levels of this toxic component are reported.

Cassava varieties are classified in sweet and bitter types according to their low or high root cyanide content. Cyanide contained in roots and other cassava plant tissues is found in two forms: free cyanide and bound or combined cyanide composed almost completely by a cyanogenic glucoside known as "linamarine". Approximately 85 to 90% of the total cyanide in cassava tissues is found as bound cyanide and only 10 to 15% as free cyanide (Gomez *et al*, 1981; Comez, 1982).

Cyanide concentration is higher in cassava peels than in the pulp or parenchyma (Wood, 1965; de Bruijn, 1973; Gomez *et al*, 1981; Gomez, 1982). Cyanide concentration varies in the leaves, with higher levels in young and tender leaves than in old leaves (Gomez and Hershey, unpublished results), but in general, leaves have concentrations similar to those found in cassava peels.

Bound cyanide or linamarine liberates hydeocyanic acid when treated with diluted acids; under natural conditions, the liberation of hydrocyanic acid is due to the enzyme linamarase, which is commonly found in cassava plant tissues especially in root peels and leaves. The contact between the enzyme and linamarine occurs when tissues suffer mechanical damages or due

717

TABLE 1. CHEMICAL COMPOSITION OF CASSAVA PRODUCTS, SORGHUM AND ALFALFA HAY.

| Components | Fresh roots | Ensiled roots | Cassava meal | Dry foliage[b] | Dry forage | Sorghum | Alfalfa hay[b] |
|---|---|---|---|---|---|---|---|
| | | | % as analized | | | | |
| Dry matter | 40-35 | 45-40 | 90 | 90-89 | 91-92 | 89-88 | 90-89 |
| Protein (Nx6.25) | 1-2 | 2-3 | 3.1 | 21 | 17-18 | 11 | 15 |
| Ether extract (fat) | 0.2-0.5 | 1-2 | 1.3 | 6-7 | 5-6 | 2.8 | 1.7 |
| Crude fiber | 1.5-2.0 | 3-4 | 3.4 | 20-24 | 17-18 | 2.0 | 29 |
| Ash | 1-2 | 2-3 | 2.1 | 8-10 | 9-10 | 1.7 | 9 |
| Non-nitrogen extract | 30-36 | 30-32 | 80 | 27-35 | 39-44 | 70-71 | 34-35 |
| Calcium | 0.05 | - | 0.12 | 1.0-1.4 | 1.75 | 0.04 | 1.4 |
| Phosphorus | 0.07 | - | 0.16 | 0.25-0.28 | 0.32 | 0.29 | 0.20 |

a  Data obtained at CIAT

b  Includes leaves and tender stems

c  From feedstuffs, Vol 53 No.30, 1981.  Ingredient analyses table.

to crushing or destruction of the cellular structure of the plant and tissues.

When roots are chopped, the proportion of free cyanide increases rapidly to 30-40% levels of total cyanide (Gomez *et al*, 1981) compared to 10-15% levels of free cyanide observed in peels or parenchyma anlyzed separately.

While the cyanide level that causes toxic effects in domestic animals has not been determined, the European Economic Community has fixed a maximum level of 100 ppm (i.e., 100 mg cyanide per kg of cassava meal) for cassava imported from Thailand. With some exceptions, specially when the initial cyanide levels are fairly high and the drying time is short, some varieties can produce roots that when dried as chips, the residual cyanide in the dry products is higher than 100 ppm. However, it is normal that sun-dried cassava chips will contain cyanide levels of less than 100 ppm and most of this cyanide is found as free cyanide that volatilizes easily (Figure 1).

Drying in ovens with forced hot air (60°C) draft also produces an efficient elimination of cyanide from fresh chips, but the amount of residual cyanide tends to be slightly higher than that obtained with natural sun-drying. Besides, the highest proportion of total cyanide in oven-dried chips is still found as bound cyanide or linamarine (Table 2)(Gomez, unpublished results).

The silage process of cassava chips also allows a rapid and total conversion of bound cyanide into free cyanide in practically 4-7 days after initiating the process, and after 4-6 months the ensiled biomass has 30% of the total initial cyanide (Gomez, unpublished results) as free cyanide. Feeding trials with pigs have demonstrated that the ensiled cassava biomass is palatable for these animals and satisfactory yields are obtained.

In summary, the natural processes to which cassava roots are subjected for animal feeding (dry or silage) are efficient means to reduce the amount of cyanide to harmless levels for these animals. However, it must be noted that fresh root chips from varieties with high cyanide contents are not consumed by pigs and, therefore, delay their growth; on the other hand, fresh roots of varieties with low cyanide contents are readily consumed and are an excellent carbohydrate source (Gomez *et al*, 1976, 1981). Consequently, roots of varieties with high cyanide contents should be processed first to eliminate most of the cyanide and for an efficient utilization by domestic animals.
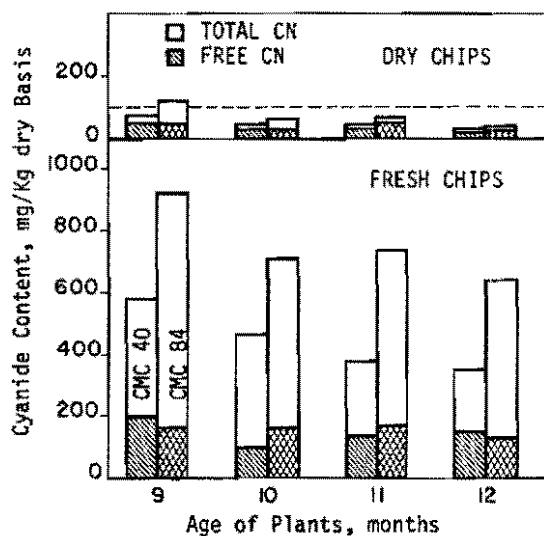
FIGURE 1.   EFFECT OF SUN-DRYING (CONCRETE FLOORS) ON CYANIDE
REDUCTION IN CASSAVA CHIPS

TABLE 2. EFFECT OF SUN-DRYING OR OVEN-DRYING ON CYANIDE ELIMI-
NATION FROM CASSAVA CHIPS.[a]

| Variety | Cyanide in fresh chips | | Type of drying | Cyanide in dry chips | |
| | Total | Free | | Total | Free |
|---|---|---|---|---|---|
| | ppm DM | % | | ppm DM | % |
| MCol 1684 | 955 | 37 | sun[b] | 114 | 79 |
| | | | oven[b] | 185 | 27 |
| MCol 113 | 290 | 30 | sun | 23 | 83 |
| | | | oven | 51 | 31 |

a   Roots of 6-months old plants

b   Sun-drying on cement floors and oven-drying at 60°C during
    24 hours.


CASSAVA UTILIZATION IN POULTRY FEEDING

In most of the tropical Latin America countries, poultry
is the agricultural sector that consume the highest proportion
(60-70%) of balanced feeds (Pachico and Lynam, 1981). Therefore,
poultry is the most important potential sector for cassava uti-
lization in animal feeding.

There is abundant information on the use of cassava meal
in bird feeding, both for broilers and for layers. Most of
the information refers to the use of cassava root meal and to
a lesser extent on the use of cassava leaf meal.

A large variability and a lack of consistency is evidenced
regarding the recommended levels of cassava meal for broilers.
Some authors suggest 10% cassava meal for the initiation diets
(0-4 weeks) and 20% for the finishing diets (4-6 or 8 weeks)
(Vogt, 1966), while other research results report good perfor-
mances with 30% levels (Montilla *et al*, 1969, 1975; Armas and
Chicco, 1973; Enriquez *et al*, 1977) and even 50% (Olson *et al*,
1969; Tejada and Brambila, 1969; Enriquez and Ross, 1967; Chou
and Muller, 1972; Armas and Chicco, 1973). Part of this vari-
ability is due to different experimental conditions employed,
specially regarding the type of processing to which the cassava

roots were subjected.

In modern poultry, diet formulation, and especially for broilers, is done by using minimum cost computer programs which are based on the price and quality of the available ingredients at the time of formulation. In Colombia, for example, if cassava meal is available at a price equivalent to 80% that of sorghum, the computer indicates that the level of cassava meal to be used should be of approximately 25% in the diet, by substituting sorghum and using fish meal, soybean meal and cottonseed meal as protein feeds or ingredients. Tables 1A and 2A in the appendix show the composition of different diets with cassava meal levels ranging between 20 and 30% for the initiation and finishing stages, respectively.

Recent research (Santos and collaborators; Gomez and collaborators, unpublished results) conducted by CIAT and the Universidad Nacional (Departamento de Zootecnia de la Facultad de Ciencias Agropecuarias en Palmira) has demonstrated the following:

a. Cassava roots with high organic cyanide contents, such as varieties MCol 1684 and CMC 84, can be processed and sun-dried to produce dry chips and then cassava meal with residual cyanide levels similar to those found in cassava products from varieties with low cyanide contents.

b. Consequently, performance differences have not been found between broilers fed with rations containing similar levels of cassava meal from roots of sweet or bitter varieties.

c. Rations containing 20 and 30% cassava meal were consumed in higher amounts and gave improved broiler performance than rations with 10% cassava meal.

d. The results obtained with cassava meal-based rations were similar to those obtained with commercial rations based on sorghum (Table 3).

e. The 5% increase in metabolizable energy in rations containing 20 and 30% cassava meal and the addition of vegetable oil produced similar weight gains and a slightly improved feed conversion (feed/gains: 2.21 vs. 2:27) than diets with no added oil (Table 3).

f. Broilers consumed approximately 4600-4700 g of balanced rations containing 20 or 30% cassava meal in an 8-week period, at the end of which they reached liveweights averaging approximately 2100 g (Table 3).

g. The costs of ingredients of cassava meal-based rations were slightly less than commercial rations based on sorghum, and therefore, similar or slightly improved economic yields

TABLE 3.  RESULTS OF RATIONS CONTAINING 20 AND 30% CASSAVA MEAL (CM) FOR BROILERS[a]

| Experimental diets | Average weight 8th-week | Feed | Feed/gains |
|---|---|---|---|
| | g | g | |
| Commercial, 0% CM | 2088 | 4667 | 2.27 |
| Control, 0% CM | 2048 | 4611 | 2.29 |
| 20% CM | | | |
|    Standard | 2153 | 4798 | 2.27 |
|    + 5% ME[b] | 2167 | 4717 | 2.21 |
| 30% CM | | | |
|    Standard | 2077 | 4638 | 2.27 |
|    + 5% ME[b] | 2141 | 4657 | 2.21 |

a   Averages for 144 broilers/group; 4 replications of 36 broilers each.

    Initial average weight: 36 g.

b   With the addition of vegetable oil a 5% increase in metabolizable energy was obtained.

were obtained with rations containing cassava meal.

Based on these data, a group of 1000 broilers will consume 4.7 tons of balanced feeds in an 8-week period of which 20 to 30% can be cassava meal (940-1400 Kg).  In case the fattening period ends at 6 weeks the consumption of balanced feeds per 1000 broilers will decrease to 2.9 tons to obtain an average weight per broiler of approximately 1500 g; in this case, the cassava meal required will be 580-870 Kg, at 20 and 30% levels, respectively.

Cassava meal levels for layers are generally higher than those for broilers.  Most of the experiments have reported levels of up to 40 to 60% and even complete substitution of cereañ grains (approximately 75%) by cassava meal.  Although slight differences exist between work published on these  topics (Temperton and Dudley, 1941; Falanghe, 1949; Enriquez and Ross, 1972; Hamid and Jalaludin, 1972; Jalaludin and Leong, 1973; Enriquez *et al*, 1977; Phalaraksh *et al*, 1978), in general, the following can be concluded:

a. Levels of approximately 50% cassava meal have given good results in rations for layers, in the initiation, growing and laying stages.

b. At these levels, no adverse effects have been observed on egg production, egg weight, shell thickness, feed conversion or bird weight.

c. With cassava meal levels of up to 25% in the ration for layers, no significant effect was observed on egg yolk color, but higher levels produced pale or discolored yolks.

d. The addition of 2-3% cassava leaf meal or synthetic pigments (xanthophylls) correct the discoloration of the yolks when high levels of cassava meal are fed to layers.

Experimental results clearly indicate that high quality cassava meal can substitute cereal grains in levels of up to 20 or 30% and 50% for broilers and layers, respectively.  Recent data also indicate that cassava roots can be used, even of varieties with high cyanide contents, provided that they are adequately processed to insure maximum elimination of this toxic compound.  The optimum utilization levels of cassava meal are a function of its price and quality.


CASSAVA UTILIZATION IN SWINE FEEDING


The European swine industry is the agricultural sector that utilizes the highest volume of cassava imported from Thailand since the cassava meal levels used in rations are higher

than those for poultry and the demand is considerably high be-
cause of the high technological level employed in the produc-
tion of this species in Europe. In Latin America as a whole,
the technological level used in swine production is very low
compared to that used in poultry, and frequently the scale of
production is for subsistence which uses no balanced feeds.
However, during the last 2 decades, several Latin American coun-
tries such as Brazil, Mexico, Cuba, Venezuela, Colombia, Ecuador
and Peru, have shown a tendency and plans to produce swine at
a commercial scale. Pork in many countries of the region ranks
second in order of importance of the total meat consumption per
capita after beef. A growing demand for balanced feeds for pigs
would mean an increased importance for cassava production in
animal feeding as a native product of tropical regions that can
well substitute most of the cereal grains.

Most of the information on cassava utilization in animal
feeding refers to swine production, due mainly to the versabil-
ity of this species to consume fresh or ensiled cassava roots,
cassava meal and even cassava leaves. Most of this information
has been obtained at CIAT as part of the Swine Production Pro-
gram and the Utilization Section of the Cassava Program (Manner,
1972; Job, 1975; Gomez *et al*, 1976, 1977, 1981; Gomez, 1977,
1979, 1981, 1982).

Both fresh and ensiled cassava roots require a supplement
to provide the protein, minerals and vitamins needed to obtain
a balanced ration; a deficient supply of these nutrients will
produce poor or antieconomic yields. This type of supplement
can be fed separately from the fresh or ensiled cassava roots,
oc an be mixed with them; however, because of the high root
moisture content, care should be taken to obtain a uniform mix-
ture of the supplement with the cassava chips. To avoid this
problem as much as possible, it is advisable to feed the supple-
ment separately in a restricted manner, but in sufficient
amounts to meet the requirements. Tables 3A and 4A in the ap-
pendix show the composition of some supplements that have given
good experimental results and a scale of the amounts of supple-
ment and fresh or ensiled cassava required according to pig age
and weight.

Table 4 summarizes the amounts of fresh cassava and pro-
tein supplements required for the different stages of the life
cycle in swine feeding programs. This feeding program is based
on experimental data using cassava roots with low cyanide con-
tent fed as chips or splinters, and can serve as a guide for
the use of ensiled roots. An interesting point to mention from
Table 4 refers to the consumption differences between chopped
cassava roots and protein supplements by growing and finishing
pigs, according to the protein level in the supplement. Cassa-
va consumption is higher when the protein supplement (fed sepa-
rately or *ad libitum*) provides higher protein levels; at the

725

TABLE 4. SWINE FEEDING PROGRAMS WITH FRESH CASSAVA ROOTS[a]

| Period | Liveweight(Kg) | | Total consumption per animal(Kg) | | % protein in PS |
|--------|---------|--------|---------|--------|--------|
| | Initial | Final | Cassava | PS | |
| Growing and finishing (98 days) | 17 | 100 | 397 | 115[b] | 43 |
| | | 96 | 381 | 72 | 43 |
| | 21 | 86 | 175 | 136[b] | 20 |
| | | | 269 | 98[b] | 30 |
| | | | 325 | 74[b] | 40 |
| Pre-gestation (60 days) | 95 | 110-120 | 240[c] | 36[c] | 40 |
| Gestation (114 days) | Reproduction | Parturition | 194[d] | 46[d] | 40 |
| | 110-120 | 150-160 | 353[e] | 71[e] | 40 |
| Lactation (56 days) | Parturition | Weaning | | | |
| | 140-150 | | 364 | 68 | 40 |

a   Values obtained using fresh roots with low cyanide content; these data can serve as a guide for using ensiled roots.

b   The protein supplement (PS) was fed separately; in the other cases, the supplement and the cassava chips were mixed

c   Values estimated based on the consumption of 4.0 and 0.6 Kg of cassava and PS, respectively

d   Grazing sows fed with 1.7 and 0.4 Kg of cassava and PS, respectively.

e   Confined sows fed with 3.1 and 0.6 Kg of cassava and PS, respectively.

same time, supplement consumption decreases (Job, 1975).

In tropical regions with high rainfall and relative humidity it is difficult to dry chopped roots to produce cassava meal. Roots are frequently harvested based on the needs, but this means that the land can not be used until all the plants have been harvested. A practical way to solve these problems is to preserve the chopped roots in a silo. Cassava chips can be compacted in ditch silos when considerable amounts of cassava are to be preserved or in polyethilene bags when dealing with small amounts. The experience at CIAT with silos built in wooden walls with a metallic sheed coating (2.3 m long, 1.5 m wide and 1.2 m high for a total volume of 4.1 m$^3$) on cement floors have allowed storing up to 5 tons of cassava chips for a 6-month period. The surface of the ensiled mass was covered with plastic over which shavings and bricks were placed to avoid air penetration; this type of ensiled mass has been evaluated in growing and sinishing pigs with good results (Gomez et al, 1981).

The trend towards commercial swine operations, even at small or intermediate scale, will lead to a growing demand for balanced feeds and consequently, to an increased cassava utilization as meal. The literature dealing with cassava meal utilization in swine feeding is extensive and, therefore, the recommendation is to review some of the publications that summarize experimental data of practical importance (Manner et al, 1967; Manner, 1972; Muller et al, 1972; Chou et al, 1973; Job, 1975; Gomez, 1977, 1979, 1981, 1982; Gomez et al, 1977, 1981; Khajarem et al, 1977; Oke, 1978).

Some additional aspects that merit special attention are the following:

Methionine supplementation in rations based on cassava meal.

The preference of animals, especially sucklings, for diets with high levels of cassava meal.

The possibility of using inputs from tropical regions such as sugarcane molasses in mixture with rations based on cassava meal, and,

The use of minimum cost formulated diets.

## Methionine Supplementation

Speculations for some time have indicated the need to supplement methionine in excess of the normal requirements, in rations with high cassava meal levels. The reasons for this recommendation were based on results of experiments with rats (Manner and Gomez, 1973) and the low reproductive rates of pregnant sows fed with rations containing cassava meal (Gomez *et al*, 1976). It was assumed that the additional supplementation of methionine played a double role in improving the protein quality of the rations and helped in the detoxification process of the residual cyanide present in cassava meals (Manner and Gomez, 1973).

Recent results with rations based on cassava meal for pregnant and lactating sows (Gomez, 1977) and for growing pigs (Gomez and collaborators, unpublished results) clearly indicate that, under normal conditions, there is no need to add more methionine than the necessary level to meet the requirements and that previous results were due to the system employed to feed the rations (group feeding) during pregnancy. It has been demonstrated that the reproductive rates are normal when each sow is fed with the rations in individual feeders. The mixture of soybean meal, fish meal and cottonseed meal meet all the methionine requirements. On the other hand, the results with sundried cassava (Gomez, 1982), indicate that the residual cyanide level in cassava meal is sufficiently low to require the addition of extra compounds, such as methionine to detoxify it.

## Nutritional Preference of Sucklings for Rations with Cassava

## Meal

The most critical stage in swine production is the lactating period and most of the success or failure and the profitability of further periods depend on the weaning results. The main objective of this stage is to reach the maximum weight at weaning and, consequently, sucklings should consume considerable amounts of the balanced feed during this stage.

Recent studies at CIAT (Gomez *et al*, 1981) clearly indicate that suckling prefer and consume higher amounts of rations containing cassava meal. Sucklings prefer and consume increased amounts of a ration containing 40% cassava meal compared to rations containing 20% cassava meal or a sorghum and soybean meal-based ration (0% cassava meal) (Table 5). The three rations with 0, 20, and 40% cassava meal each in a separate feeder, were continuously available for suckling during the experimental period. These data indicate that rations based on cassava meal are more palatable and prefered by suckling and allow obtaining very good yield results of the litters at weaning.

728

ABLE 5.  COMPARATIVE CONSUMPTION OF RATIONS CONTAINING DIFFER-
ENT CASSAVA MEAL LEVELS FOR SUCKLINGS.*

| Cassava meal level[b] | Stage, days | | Total consumption 14-56 days |
|---|---|---|---|
| | 14-42 | 42-56 | |
| | | Kg/litter | |
| 0 | 1.8 | 14.7 | 16.5 |
| 20 | 3.0 | 26.2 | 29.2 |
| 40 | 12.4 | 39.1 | 51.5 |
| Totals | 17.2 | 80.0 | 97.2 |

* Averages from 10 first parturition litters

## Cassava Meal and Sugarcane Molasses

In tropical countries where sugarcane is a widespread crop, the possibility of using high levels of sugarcane molasses to substitute partially and progressively some basic energy ingredients, offers the advantage of improving the palatability of the rations, thus promoting increased consumption and consequently, rapid and economic weight gains.  In the case of rations based on cassava meal, molasses also improves the physical appearance of the reations since it reduces its powdery nature.

A ration with 18% protein based on cassava meal (59.5%), soybean meal (34.3%), bone meal (5.0%), mineral and vitamin premix (0.3%), iodized salt (0.6%), and methionine (0.3%), can be mixed with increasing levels of sugarcane molasses in the proportions shown in Table 6 to feed growing and finishing pigs (weaning at slaughtering weight).  Based on this feeding program, as the proportional molasses increases the amount of cassava meal in the ration decreases, such that protein supply is reduced progressively from 17 to 12%, from the beginning to the end of the fattening period and the molasses levels increase from 5 to 35% in the total rations (Table 6).

The results of this research are presented in Table 7 were compared with yields from a control ration based on maize.  Pigs fed with the cassava meal ration and increasing levels of molasses reached a higher liveweight (97.6 vs. 93.7 Kg) and one week before the control rations.  While at the present prices (1982)

TABLE 6. MIXTURES OF A RATION BASED ON CASSAVA MEAL AND INCR-
EASING LEVELS OF SUGARCANE MOLASSES FOR FATTENING
PIGS.

| Liveweight range | Time | Basal ration with 18% protein | Sugarcane molasses % | % Protein in ration |
|---|---|---|---|---|
| Kg | weeks | % | % | % |
| 20-25 | 0-2 | 5 | 95 | 17.1 |
| 25-35 | 2-5 | 10 | 90 | 16.2 |
| 35-50 | 5-8 | 15 | 85 | 15.3 |
| 50-60 | 8-10 | 20 | 80 | 14.4 |
| 60-70 | 10-12 | 25 | 75 | 13.5 |
| 70-80 | 12-13 | 30 | 70 | 12.6 |
| 80-95 | 13-14 | 35 | 65 | 11.7 |

of the basic ingredients, the total feeding cost is similar for
both groups, the one fed on cassava meal rations and increasing
levels of molasses would produce improved weight gains and suf-
ficient time to reach the slaughtering weight; therefore, the
economic benefit would be higher.

These results demonstrate the feasibility of using cassava
meal and sugarcane molasses efficiently as the basic ingredients
in swine feeding to substitute cereal grains completely; however,
since both provide limited protein, the required amounts of soy-
bean meal or other protein ingredients would be higher than that
needed to supplement sorghum or maize.

Cassava meal and minimum cost diets

The formulation of balanced feeds for commercial swine ope-
rations is done, as in the case of poultry, through minimum cost
computer programs. Tables 5A and 6A in the appendix show the
composition of diets for pigs obtained with cassava meal, at a
price equivalent to 80% that of sorghum. In the case of pigs,
it can be noted that ingredients such as sugarcane molasses can
be incorportated at higher levels than those of poultry. Expe-
rimental results with pigs also suggest that rations for this

730

TABLE 7. CASSAVA MEAL UTILIZATION WITH INCREASING LEVELS OF MOLASSES FOR FATTENING PIGS.

| Parameter | Control (maize) | Cassava meal + molasses |
|---|---|---|
| No. days of trial | 119 | 112 |
| Average weight/pig, Kg | | |
| Initial | 17.3 | 16.9 |
| Final | 93.7 | 97.6 |
| Daily gains, Kg | 0.64 | 0.72 |
| Total consumption/pig, Kg | | |
| Total ration | 228 | 265 |
| Maize or cassava meal | 189 | 121 |
| Molasses | - | 62 |
| Soybean meal | 28 | 70 |

species can include higher cassava meal levels than for poultry.

While in practice minimum cost rations for pigs would contain 30-40% cassava meal levels, Table 8 shows the amount of ration required for each stage of the pig's life cycle, using cassava meal to substitute all cereal grains and using soybean meal as the only protein source. The difference between the addition of the amounts of cassava meal and soybean meal, and the amount of total diet, is represented by the mineral and vitamin supplement required to meet the needs of these nutrients.

TABLE 8. AMOUNT OF TOTAL RATION AND BASIC INGREDIENTS FOR A FEEDING PROGRAM WITH CASSAVA MEAL AND SOYBEAN MEAL FOR THE LIFE CYCLE OF A PIG (in Kg).

| | S t a g e | | | |
| Feed | Growing and finishing | Pregestation and gestation | Lactation sow | sucklings |
|---|---|---|---|---|
| Total ration | 216 | 428 | 293 | 51 |
| Cassava meal | 158 | 311 | 196 | 26 |
| Soybean meal | 48 | 97 | 83 | 18 |

CASSAVA UTILIZATION IN RUMIANT FEEDING-STORAGE CASSAVA

Because of its chemical composition, the most adequate use of cassava roots and its products is for feeding non-rumiants, specially poultry and swine. On the other hand, the availability of extensive areas for pasture production in most Latin American regions forces the use of extensive grazing systems for milk and beef cattle production. However, the trend in certain areas to use intensive production systems, especially for milk cattle production, allows considering the use of cassava by-products in rumiant feeding.

While cassava root meal could be used for calve feeding and in supplement for highly productive milk cows, one of the potential uses of cassava for rumiant feeding is the utilization of leaves or foliage (leaves and tender stems) of plants seeded for root production. These parts of the plants would

practically be a by-product of the cassava crop. Depending of the part of the plant, its chemical composition will vary considerably. If only the leaves are used, the protein content would be around 23-28% on a dry basis, but if petioles and apical green branches are included, the protein content would be reduced to 18-21%; an inverse relationship would be observed for the fiber content that is normally around 9% for leaves alone, but increases to 20-25% when all the top young part of the plant is incorporated. The harvesting of leaves alone, demands much labor and the total production of leaves varis considerably between cassava varieties and can be affected by climatic (specially rainfall), edaphic and biotic (pests and diseases) factors. Therefore, the production costs of cassava leaves or a dry product (meal) through sun-drying would be too high to justify their harvesting for rumiant nutrition; this type of product could be used as a protein feed for monogastric animals or to provide natural pigments in rations, specially when they contain high levels of cassava root meal for layers.

Although the foliage (leaves and tender stems) of cassava planted to produce roots have been scarcely explored as a potential for animal feeding, more agronomic data are required to determine the optimum conditions required to obtain maximum yields. More detailed studies are required on aspects such as the possibility of pruning at least part of the tops during the vegetative cycle of the plant and its effects on root yields, as well as the selection of varieties with high foliage production.

The production of forage cassava represents the highest utilization potential of this crop for feeding rumiants. Increasing the number of plants per hectare to 111,000 through plantings at 30 x 30 cm distances, a dry matter yield of over 30 tons/ha a year were obtained with four harvestings (at 90-day intervals) of all the top part of the plant (Moore, 1976). When the number of harvests per year or the amount of plants per hectare were reduced, cassava forage production also decreased.

Cassava forage has a high nutritional value for rumiants. Cassava forage meal used to feed milk cows has shown to have almost the same nutritional value of alfalfa hay (Echandi, 1952). mixtures of 75-25% elephant grass and 50-50% fresh cassava forage produced improved weight gains in fattening steers compared to the use of elephant grass alone (Moore, 1967) and these results were mainly obtained because of the high protein level provided by cassava forage. The possibility of producing cassava forage silage can increase its potential even more for use in intensive cattle operations.

Forage cassava can be sun-dried also to produce hay that can be milled to produce meal; the chemical composition of this

type of meal was shown in Table 1. As can be observed, its nutrient contents compares favorably with that of alfalfa hay. Relatively high levels of forage cassava meal can be used in rations for pregnant sows, but because of their high fiber content, its use is restricted for growing pigs or broilers.

Recent reports indicate that, in addition to the cyanide content, cassava forage contains condensed tannins that can reduce protein digestibility possibly as a result of the aforementioned non-digestible tannin-protein complexes or because of the effects of tannins on proteolytic enzyme activity (Reed *et al*, 1982). The formation of tannin-protein complexes will be very important in rumiant nutrition since they can cause a reduction in the protein value of cassava forage; the inhibitory effects of tannins on the utilization of cassava foliage or forage meal would be of great importance for monogastric animals and would explain the results of previous nutritional evaluations carried out with these types of products in poultry (Ross and Enriquez, 1969), swine (Gomez *et al*, 1981) and laboratory animals (Eggum, 1970).

Because of these reasons, it is evident that the potential use of cassava roots, foliage and forage in rumiant feeding has promising perspectives in the future. Forage cassava production, however, requires more detailed studies regarding agronomic aspects, the factors that can affect the nutritional quality and the profitability of this type of crop compared to that of crops traditionally used for rumiant feeding.

CONCLUSIONS

Cassava roots represent approximately 50% of the total plant weight at harvesting between 9 and 12 months of age. Whole roots can be used in animal feeding, specially for poultry and swine, as meal that is obtained after chopping the whole roots into chips or splinters, sun-drying them and then milling the dry chips to incorporate them as meal into balanced feeds. Fresh or ensiled roots can also be used for swine and cattle feeding.

Cassava foliage represents 10-15% of the total plant weight and can be used as fresh foliage for cattle feeding. Dry foliage is a significant source of protein that can be used for feeding poultry and swine. The high concentration of natural pigments in this product turns it into a supplement of these compounds for layer feeding, specially when the rations contain high levels of cassava root meal. The woody part of the stem is normally used to obtain stakes for the vegetative multiplication of the crop.

In spite of the nutritional qualities of the different parts of the cassava plant, and especially the roots, their utilization in animal feeding in most Latin American countries is relatively limited. One of the reasons that explains this situation is the high price of fresh roots as a result of the limited production of the crop, mostly for human consumption. The prospects of increasing cassava utilization for animal nutrition will become a reality when sufficiently low prices of the raw material are obtained as a result of production increases, allowing its processing for this market. High yielding varieties as well as improved agronomic practices to increase productivity appear to be strategies as promising as that of increasing the cropping area.

At the utilization level, the most important factors that should be considered are the price of the cassava meal or product and its quality, compared to the ingredients that will be substituted in balanced feeds. In Latin America, the most attractive market for cassava root meal utilization in animal feeding is poultry, and to a lesser extent swine production. For substitution purposes it is necessary to consider that cassava meal would have a price equivalent to 80-85% that of sorghum or maize; in case the price of the cassava meal was less, the levels in the rations for domestic animals, specially pigs, could be increased.

While cassava root utilization for animal feeding is one of the most economically important alternative market, to restrict the increasing importation of cereal grains, there are other uses that, depending on the local conditions, would eventually be as profitable or more than animal feeding. Local or regional economic feasibility studies of cassava agroindustrial development programs oriented to meet animal production demand should be conducted to estimate the probability of success.

TABLE 1A.  MINIMUM COST INITIATION RATIONS (0-4 WEEKS) CON-
TAINING CASSAVA ROOT MEAL FOR BROILERS

| Price[a] | Ingredient | Cassava meal levels, % | | |
|---|---|---|---|---|
| | | 0 | 20 | 30 |
| $/Kg | | Percentages | | |
| 15 | Sorghum | 67.09 | 44.32 | 32.94 |
| 12 | Cassava meal | ... | 20.00 | 30.00 |
| 29 | Soybean meal | 21.52 | 22.68 | 23.25 |
| 35 | Fish meal-65 | 8.00 | 8.00 | 8.00 |
| 38 | Animal fat | 0.44 | 1.89 | 2.62 |
| 14 | Bone meal-vapor | 2.24 | 2.38 | 2.45 |
| 10 | Salt | 0.25 | 0.25 | 0.25 |
| 168 | Commercial premix | 0.20 | 0.20 | 0.20 |
| 280 | Methionine | 0.11 | 0.13 | 0.14 |
| 300 | Coccidiostate | 0.10 | 0.10 | 0.10 |
| 228 | Antibiotic | 0.05 | 0.05 | 0.05 |
| | Estimated nutrients, % | | | |
| | Protein | 22.13 | 21.18 | 20.70 |
| | Calcium | 0.93 | 0.97 | 0.99 |
| | Phosphorus | 0.50 | 0.50 | 0.50 |
| | Available phosphorus | 0.24 | 0.25 | 0.26 |
| | Lisine | 1.20 | 1.20 | 1.20 |
| | Methionine | 0.50 | 0.50 | 0.50 |
| | Metabolizable energy Kcal/Kg | 2,950 | 2,950 | 2,950 |
| | Cost. $/Kg | 20.67 | 20.62 | 20.59 |

a    Prices as of June, 1982 (1 US$ = 60 Colombian pesos).

TABLE 2A.  MINIMUM COST FINISHING RATIONS (4-8 WEEKS) CON-
TAINING CASSAVA ROOT MEAL FOR BROILERS.

| Price[a] | Ingredient | Cassava meal levels, % | | |
|---|---|---|---|---|
| | | 0 | 20 | 30 |
| $/Kg | | Percentages | | |
| 15 | Sorghum | 70.94 | 48.17 | 36.79 |
| 12 | Cassava meal | ... | 20.00 | 30.00 |
| 29 | Soybean meal | 19.55 | 20.70 | 21.28 |
| 35 | Fish meal-65 | 5.00 | 5.00 | 5.00 |
| 38 | Animal fat | 1.07 | 2.53 | 3.25 |
| 14 | Bone meal-vapor | 2.65 | 2.79 | 2.85 |
| 10 | Salt | 0.32 | 0.32 | 0.32 |
| 168 | Commercial premix | 0.20 | 0.20 | 0.20 |
| 280 | Methionine | 0.13 | 0.15 | 0.16 |
| 300 | Coccidiostate | 0.10 | 0.10 | 0.10 |
| 228 | Antibiotic | 0.05 | 0.05 | 0.05 |
| | Estimated nutrients, % | | | |
| | Protein | 19.67 | 18.72 | 18.25 |
| | Calcium | 0.88 | 0.92 | 0.94 |
| | Phosphorus | 0.48 | 0.48 | 0.48 |
| | Available phosphorus | 0.28 | 0.29 | 0.30 |
| | Lisine | 1.00 | 1.00 | 1.00 |
| | Methionine | 0.45 | 0.45 | 0.45 |
| | Metabolizable energy Kcal/Kg | 3,000 | 3,000 | 3,000 |
| | Cost $/Kg | 19.98 | 19.92 | 19.89 |

a    Prices as of June, 1982 (1 US$ = 60 Colombian pesos)

TABLE 3A.   PROTEIN SUPPLEMENT COMPOSITION FOR USE WITH FRESH OR
ENSILED CASSAVA ROOTS.

| Ingredients | Cotton + soybean | Soybean | Cotton + fish meal | Fish meal |
|---|---|---|---|---|
| | Percentages | | | |
| Cottonseed meal (42.9)[a] | 44 | ... | 48.5 | ... |
| Soybean meal (48.8) | 44 | 88 | ... | ... |
| Fish meal(53.9) | ... | ... | 48.5 | 97 |
| Bone meal | 9 | 9 | ... | ... |
| Salt | 2 | 2 | 2 | 2 |
| Commercial premix | 1 | 1 | 1 | 1 |
| | | | | |
| Estimated nutrients, % | | | | |
| Protein | 41.0 | 43.6 | 47.5 | 52.3 |
| Calcium | 2.02 | 2.04 | 5.2 | 11.5 |
| Available phosphorus | 1.14 | 1.12 | 2.2 | 5.6 |

a    Figures in parenthesis indicate the amount of protein

TABLE 4A.  AMOUNT OF PROTEIN SUPPLEMENT (42% PROTEIN) TO BE
           FED DAILY WITH FRESH OR ENSILED CASSAVA ROOTS FOR
           GROWING AND FINISHING PIGS.

| Liveweight range Kg | PS g | Protein provided g | Fresh or ensiled[a] cassava Kg |
|---|---|---|---|
| 15-20 | 500 | 210 | 1.0-1.2 |
| 20-35 | 600 | 252 | 1.2-2.5 |
| 35-50 | 700 | 294 | 2.5-3.5 |
| 50-70 | 800 | 336 | 3.5-4.5 |
| 70-95 | 950 | 400 | 4.5-6.0 |

a   The amount of fresh or ensiled cassava roots will be esta-
    blished according to the daily consumption observed; the
    amounts indicated can serve as a guide.

TABLE 5A.  MINIMUM COST RATIONS CONTAINING CASSAVA ROOT MEAL
FOR GROWING AND FINISHING PIGS

| Price[a] | Ingredient | Cassava meal levels in rations for | | | |
| | | Growing | | Finishing | |
| | | 0 | 30 | 0 | 30 |
|---|---|---|---|---|---|
| $/Kg | | Percentages | | | |
| 15 | Sorghum | 66.90 | 35.50 | 71.45 | 37.83 |
| 7 | Molasses | 10.00 | 10.00 | 15.00 | 15.00 |
| 12 | Cassava meal | ... | 30.00 | ... | 30.00 |
| 30 | Soybean meal | 3.64 | 5.48 | 0.29 | ... |
| 21 | Cottonseed meal | 12.00 | 11.46 | 5.71 | 9.38 |
| 33 | Fish meal | 5.00 | 5.00 | 5.00 | 5.00 |
| 14 | Bone meal-vapor | 1.32 | 0.95 | 1.88 | 1.00 |
| 2 | Calcium carbonate | 0.49 | 0.96 | 0.03 | 0.71 |
| 10 | Salt | 0.39 | 0.39 | 0.39 | 0.39 |
| 160 | Commercial premix | 0.20 | 0.20 | 0.20 | 0.20 |
| 240 | Antibiotics | 0.05 | 0.05 | 0.05 | 0.05 |
| 38 | Animal fat | ... | ... | ... | 0.43 |
| | Estimated nutrients % | | | | |
| | Protein | 16.86 | 15.36 | 13.16 | 12.18 |
| | Calcium | 0.84 | 0.96 | 0.80 | 0.89 |
| | Phosphorus | 0.62 | 0.64 | 0.60 | 0.60 |
| | Available phosphorus | 0.14 | 0.10 | 0.20 | 0.10 |
| | Lisine | 0.70 | 0.70 | 0.50 | 0.50 |
| | Methionine | 0.29 | 0.26 | 0.23 | 0.22 |
| | Metabolizable energy Kcal/Kg | 3.15 | 3.15 | 3.15 | 3.15 |
| | Cost $/Kg | 16.67 | 15.96 | 15.45 | 14.74 |

a  Prices during early 1982 (1 US$ = 60 Colombian pesos)

TABLE 6A.  MINIMUM COST RATIONS CONTAINING CASSAVA MEAL FOR LACTATING SOWS AND SUCKLINGS.

| Price[a] | Ingredient | Cassava meal levels in rations for | | | |
|---|---|---|---|---|---|
| | | Lactating sows | | Sucklings | |
| | | 0 | 30 | 0 | 40 |
| $/Kg | | | | | |
| 15 | Sorghum | 67.30 | 30.40 | 65.29 | 20.94 |
| 12 | Cassava meal | ... | 30.00 | ... | 40.00 |
| 7 | Molasses | 13.00 | 15.00 | 5.00 | 5.00 |
| 21 | Cottonseed meal | 8.00 | 8.00 | 5.00 | 5.00 |
| 35 | Fish meal | 5.00 | 5.00 | 5.00 | 5.00 |
| 29 | Soybean meal | 4.20 | 8.50 | 15.61 | 19.32 |
| 14 | Bone meal-vapor | 1.53 | 0.95 | 1.53 | 0.95 |
| 2 | Calcium carbonate | 0.22 | 0.98 | 0.85 | 1.10 |
| 55 | Vegetable oil | ... | 0.55 | 1.06 | 1.99 |
| 10 | Salt | 0.40 | 0.40 | 0.39 | 0.39 |
| 128 | Commercial premix | 0.20 | 0.20 | 0.20 | 0.20 |
| 228 | Antibiotic | 0.05 | 0.05 | 0.05 | 0.05 |
| 280 | Methionine | 0.017 | 0.029 | 0.029 | 0.053 |
| | Estimated nutrients % | | | | |
| | Protein | 15.54 | 15.00 | 19.30 | 18.00 |
| | Calcium | 0.80 | 1.00 | 1.00 | 1.00 |
| | Phosphorus | 0.60 | 0.61 | 0.62 | 0.65 |
| | Available phosphorus | 0.16 | 0.10 | 0.16 | 0.10 |
| | Lisine | 0.65 | 0.73 | 0.95 | 1.00 |
| | Methionine | 0.28 | 0.28 | 0.35 | 0.35 |
| | Metabolizable energy Kcal/Kg | 3.15 | 3.15 | 3.27 | 3.33 |
| | Cost $/Kg | 16.37 | 16.09 | 18.80 | 18.35 |

a   Prices as of March, 1982 (1 US$ = 60 Colombian pesos)

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