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CIAT is a nonprofit organization devoted to the agricultural and economic development of the lowland tropics. The government of Colombia provides support as a host country for CIAT and furnishes a 522-hectare site near Cali for CIAT's headquarters. In addition, the Colombian Foundation for Higher Education (FES) makes available to CIAT a 184-hectare substation in Quilichao and a 73-hectare substation near Popayán; the Colombian Rice Federation (FEDEARROZ) also makes available to CIAT a 30-hectare farm—Santa Rosa substation—near Villavicencio. CIAT co-manages with the Colombian Agricultural Institute (ICA) the 22,000-hectare Carimagua Research Center in the Colombian Eastern Plains and carries out collaborative work on several other ICA experimental stations in Colombia; similar work is done with national agricultural agencies in other Latin American countries. CIAT is financed by a number of donors, most of which are represented in the Consultative Group for International Agricultural Research (CGIAR). During 1984 these CIAT donors are the governments of Australia, Belgium, Canada, France, the Federal Republic of Germany, Italy, Japan, the Netherlands, Norway, Spain, Sweden, Switzerland, the United Kingdom, and the United States of America; the European Economic Community (EEC); the Ford Foundation; the German Agency for Technical Cooperation (GTZ); the Inter-American Development Bank (IDB); the International Development Research Centre (IDRC); the International Fund for Agricultural Development (IFAD); the OPEC Fund for International Development; the Rockefeller Foundation; the United Nations Development Programme (UNDP); the United Nations Food and Agriculture Organization (FAO); the World Bank; and the W. K. Kellogg Foundation.

Information and conclusions reported herein do not necessarily reflect the position of any of the aforementioned entities.

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INTRODUCTION

The increased interest in cassava in Latin America due to the severe foreign debt problems has given new impetus to the demand for assistance in this region. In Asia, the full-time, core-financed staff member is already having a major positive impact on CIAT's cooperation in the area. CIAT's sister institute IITA has major responsibility for Africa, nevertheless CIAT continues to have an important role in this area by providing basic research information, germplasm and biological control agents.

Latin America and the Caribbean.

In March 1984, top level administrators of the national research and extension programs of five countries were invited to a workshop on the development of integrated cassava production, processing and marketing projects. The workshop included discussion on the philosophical basis of these projects, their management and also visits to the processing plants - a successful implementation of this approach -located on the North Coast of Colombia.

Two notable tendencies were observed at the workshop. First national program leaders exchanged views and experiences and requested assistance not only from CIAT but also from each other in the development of new projects. Second, the participants unanimously agreed that the economic situation in Latin America is such that each country must exploit its indigenous resources, one of which is cassava, to satisfy its growing requirements for carbohydrates for human or animal feed.

A direct result of the workshop was a request from Mexico for assistance in the development of priorities for cassava production and processing in that country. CIAT and INIA (Instituto Nacional de Investigaciones Agrícolas) then participated in a workshop to orient personnel from the Secretariat for Agriculture and Water Resources in Mexico city. A joint team of INIA (Instituto Nacional para Investigacion Agricola) and CIAT has now produced a working document defining the areas of Mexico with greatest potential for cassava production, processing and marketing (for the methodology used and the most important results see the Economics Section of this report). As a direct result of these efforts, Mexico is establishing 20 drying plants and multiplying planting material of selected varieties for distribution to farmers.

In Brazil, a team of CIAT scientists was invited to attend the national cassava program planning forum in April. A notable change has occurred in that program's research strategy. Previously, breeding activities were concentrated on just one major site, however, a decentralized program is being set up with regional centers for breeding and selection. This strategy parallels that adopted by CIAT in the late 70's and early 80's which is proving much more effective than the previous more centralized efforts.

In northern Brazil, a variety selected from CIAT hybrid seed is being multiplied for release.

Another major advance in the program was the instigation of efforts to define the future demand potential of cassava in Brazil so as to more clearly orient the research program. CIAT was asked to assist in this process and has acceded to the request.

In Panama, CIAT and IDIAP (Instituto de Investigacion Agricola Panamena) have collaborated closely on the first phase of the development of an integrated cassava drying project for animal feed. A drying patio was built in Panama (adapted for Panamanian conditions) and

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was successfully operated by a farmers' group. New production technology was tested on a semi-commercial scale and new varieties introduced for testing this coming year. The local variety "Brasilena" (which is M Pan 51 already released as "Sabanera" in Mexico) has been selected as a promising variety and is being multiplied for release to farmers. In addition, IDIAP carried out with CIAT assistance a production course for extension agents in Panama.

In Cuba, CIAT participated in a short training course for Cuban professionals. The Cuban program is now firmly established and germplasm is being sent via meristem culture for evaluation in the edaphoclimatic zone (ECZ) 6. Results of this evaluation will enable CIAT to make and send more appropriate crosses in the future.

In Cuba, selection of local varieties, release of introduced varieties and new hybrids coupled with improved "seed" production schemes and the use of the "Colombian system" of production has had a dramatic impact on cassava production. The productivity per hectare has been increased with reduced use of inputs such as irrigation and insecticides. The national average yield has doubled from 5-6 t/ha in the 70's to over 12 t/ha on some 20,000 ha of state farms and cooperatives. The estimated value of this increased production is approximately US$ 5 million/year.

In Colombia, the DRI (Integrated Rural Development) project for the production of cassava chips for use in animal feed has moved ahead. (DRI contracts CIAT in an advisory role in this project.) The number of commercial drying plants had increased to seven by early 1984 and is being expanded to 20 for early 1985. The clone M Ven 156 which performed well in the (Instituto Colombiano de Agricultura) ICA-CIAT regional trials on the Colombian North Coast for more than five years, was released as the variety Manihoica P 12. This variety has been cleaned by meristem culture and is being multiplied for distribution to farmers. In the department of Magdalena farmers have the material and the variety is already widely grown. The variety CMC 40 was also extensively tested by ICA-CIAT and has been released as Manihoica P 11.

In the english-speaking West Indies there has been a renewed interest in cassava. A mission from CARDI (Caribbean Agricultural Research Development Institute) with representatives from Jamaica, Trinidad and Barbados, visited CIAT on a fact-finding mission. Arrangements were made for future cooperation and germplasm exchange. With respect to the latter, guidelines were established for sending *in vitro* cultures to Trinidad (as the distribution center is in the West Indies). The first material has already been dispatched.

An intensive training course for 29 participants from Latin America was held at CIAT and 18 of the participants later completed a specialization phase. The presence of three Paraguayans indicated a new interest on the part of Paraguay, in which cassava is of great importance, to improve production and processing technology.

Africa

In the CGIAR system, CIAT has global responsibility for cassava research and IITA (International Institute of Tropical Agriculture, Nigeria) has the regional responsibility for Africa. CIAT does much of the basic research on cassava which can have an impact on cassava production and utilization on a global basis, despite the fact that the research and development is carried out in Latin America.

The CIAT germplasm collection and development of elite lines is of great importance to Africa and while CIAT does not have a breeding program in Africa, its efforts are channeled through the comprehensive IITA program. Over the years, the IITA program has been the biggest single recipient of sexual seed from CIAT; over 70,000 genetically distinct sexual seeds have increased the IITA gene pool and in the past crosses have mainly been directed to this goal. However, this year, CIAT has started making crosses, with specific characteristics for dispatch to IITA,. Thus, emphasis has been placed on producing elite pools of materials with resistance to the green spider mite and also materials for the highland cassava growing areas of Africa.

A major problem with most CIAT germplasm sent to Africa has been the lack of resistance to African mosaic disease (AMD). Due to quarantine restrictions it has not been possible to introduce to IITA clones most resistant to the green spider mite for crossing with AMD resistant or tolerant clones. Recently, IITA and CIAT have agreed to send AMD tolerant clones to CIAT after passing through a quarantine period in the United Kingdom. At CIAT, they can be crossed with mite resistant materials and the progeny (as sexual seed) returned to IITA for testing and selection. This is a major breakthrough that should enable the two centers to provide clones more rapidly to the African farmers that combine AMD and green spider mite tolerance.

The green spider mites and mealybugs are estimated to cause billions of dollars in losses per year to African farmers but these pests are native to the Americas. In the long run, resistant or tolerant varieties must be produced, although biological control offers a partial short term solution to the problem. The identification of the cassava mealybug Phenacoccus manihoti in Paraguay by CIAT some years ago (before this time it was not known the mealybug existed there) allowed the systematic collection of biological control agents. Collection of biological control agents in the eastern plains of Colombia followed by studies at CIAT headquarters have led to the identification of predators and parasites of P. herreni and one of these was effective in the control of P. manihoti in Africa. Similarily Phytoseiid predatory mites sent from CIAT to IITA have proven effective for green spider mite control in preliminary field trials. Much of the work on mass rearing of these biological control agents which was done at CIAT headquarters is directly applicable to the African biological control program.

While there is a clear transfer of genetic resources to Africa for biological control and germplasm improvement, in many cases flow of information to produce a positive impact of CIAT's work in the African context is not as obvious. One concrete example is the development of rapid propagation methods pioneered at CIAT. In a recent paper at the

Second Symposium of the African Branch of the International Tropical Root Crops Society on rapid propagation 3 of the 5 references cited work done at CIAT. These methods, after minor modifications for African conditions have been used to accelerate food programs in Nigeria to provide farmers with stocks of the new high yielding clones developed by IITA.

There are other examples of potential use of information in Africa and a few of the more salient examples are given below. Much of the basic information on etiology and epidemiology of diseases of cassava particularly cassava bacterial blight (CBB), have formed the basis of much work in Africa. The result of work on erosion control, fertility maintenance, mycorrhizal associations and mixed cropping patterns should all be applicable in Africa. Recently, IITA has requested from CIAT complete information on the techniques to control post harvest deterioration of cassava at the farm level. The interchange of information is not, however, a one-way street and IITA will be contributing to the CIAT Cassava newsletter, and link in with the world cassava documentation center.

Asia

The CIAT breeding effort in Asia is now established and in the future the Cassava Program will expand its activities in this region. To orientate these future activities in Asia a series of economic studies on the potential for cassava in Asia was carried out and formed the basis of a workshop held in Bangkok from June 5-8 on "The Future Potential of Cassava in Asia and Research Development Needs". The workshop, organized by CIAT and CGPRT (Coarse Grains, Pulses, Roots and Tuber Crops Centre) and partially funded by the Ford Foundation, was attended by 56 participants from national and international agencies. The main conclusions of this workshop are described below.

Beyond the central role that rice plays in the food economies of tropical Asian countries, the agricultural sectors of these countries are very diverse. Cassava production and utilization has adapted itself to this diversity when comparing cassava sectors across countries it is the differences rather than the similarities that are most striking. Cassava has developed within different types of land constraints, and multiple markets have evolved around the crop, with the particular market structure reflecting the overall development of the economy. The rate of development of most of these economies has accelerated over the past two decades, creating a potential demand for broadening both cassava production and utilization.

Rapid development of the crop will depend, in most cases, on yield increases, either to relieve land constraints or to be competitive in these emerging markets. Within the Asian context, where expansion of crop area is frequently constrained, it is natural that there should be a bias toward crops with very high yield potential, and even more so under upland conditions. Very high productivity is already being achieved in certain areas but in general average yields remain below the known potential of the crop. What still remains largely undefined is the means of achieving this high-yield capability across tropical Asia. Obviously, the type of technology will necessarily vary, requiring a

continued commitment of research resources to maintain the cassava research capacity in Asia that has emerged over the last two decades since the founding of the Indian program in 1963. Governments, however, require justification for the research investment, which follows from the role cassava could play in the policy area.

Given its adaption to a wide range of upland conditions and its multiple-use characteristics, cassava is a substantially flexible crop for agricultural policy so that cassava can meet multiple policy objectives. Increased cassava production with lowered costs will first be used for human consumption in fresh or dried form. In India and Indonesia, for example, cassava can play a clear role in nutrition policy. As this demand is satisfied, dried cassava can readily move into animal feed markets, which are increasing so rapidly at present that they can only be satisfied by increased imports of cereal grains.

Because of its multiple-market potential, cassava can play a major role as a source of income generation for small-scale farmers in upland areas in all countries including India and Indonesia. Increased production will also bring socioeconomic benefits to rural areas. For example, while the labor force used in cassava cultivation varies widely, with very intensive labor use in southern India and Indonesia, for every two hectares of cassava planted, one more person gains the equivalent of full employment for one year. Moreover, cassava processing is highly labor intensive and uses equipment that can readily be manufactured by local blacksmiths; thus processing will create employment and stimulate local industry. In Thailand, for example, it has been estimated that 8-10 million people receive direct or indirect benefits from the rapid expansion of the Thai cassava industry.

A further advantage in satisfying growing domestic markets by increased domestic production is the positive impact on the balance of payments. Further market diversification of cassava will, however, require both improved production and appropriate processing technologies, together with better integrated markets in most countries.

The Green Revolution that swept the continent in the late sixties and the seventies was limited to irrigated areas. The next major challenge is to raise crop productivity and farmer incomes in the upland areas. With probably limited prospects for further major growth in the world demand for rubber, palm oil and coconut oil; with growing domestic markets that could absorb cassava products; and with a growing regional market for carbohydrate sources for livestock, cassava is a major, if not the major, crop in a position to foster income growth in the upland areas of tropical Asia.

Recommendations[a]

One of the significant outputs of the cassava workshop was the preparation of research recommendations covering four fields; breeding, agronomy and cropping systems, post-harvest technology, and economics.

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a The following was taken from the "Palawija News" Vol 1 N°. 1. CGPRT Centre, Bogor, Indonesia.

These may not only facilitate the task of national research planners but may also serve as guidelines for future co-operative work on cassava in the region. The recommendations are only briefly outlined here.

Breeding. More productive varieties are of strategic importance to increase yields and to reduce production costs. This includes the collection and characterization of local germplasm, the introduction and selection of Latin American germplasm, and hybridization between these two. Selection targets are primarily high yield and dry matter content, and also early maturity and adaptation to intercropping. Specific targets for certain areas include adaptation to various soil and climatic conditions, tolerance to shade, better quality tubers for fresh consumption, and tuber characteristics facilitating harvest. The need to maintain strictly controlled release schemes was questioned, since this may delay the final release of new cultivars, and since farmers may often be in a better position to select cultivars most appropriate to their specific conditions.

Agronomy. The maintenance of soil fertility through the use of crop rotation and organic fertilizers has high priority; existing data should be used as a basis for regional research directed to establishing the principles of fertility maintenance.

Other priority areas include: developing technologies to ensure the availability of food planting material if early maturing ones are developed; seeking appropriate forms of weed control for various cropping systems; and adapting erosion control measures already tested at CIAT or elsewhere.

Intercropping with annual crops is now well known and only needs adaptation at the local level. The long term effect of cassava on subsequent performances of tree crops needs to be established, as does the physiology of cassava growth and development in shade conditions to ascertain the possibility of obtaining good yields in such conditions. Finally, the development of a typology of cropping systems in the region could lead to more effective transfer of information obtained in each system in the region.

Research on post-harvest technology might be best organized at the regional level, whether it is directed (a) to developing new technologies, or (b) to sharing improved techniques which have been successfully developed by countries in the region. A research priority falling into the first category is the question of how to extend the shelf life of dried cassava, either in factory warehouses or under family storage; this is also the case for studies on the economic feasibility of production of products such as cassava flour, modified starch, alcohol, single cell protein (SCP), and high fructose syrup (HFS). In the second category is the sharing of small scale starch production and dried cassava processing methods, and of technologies practiced in the region to decrease post harvest losses, or to utilize starch by products. A multitude of cassava products exists within the region and elsewhere, but little information has been disseminated on processing techniques or on final products.

The agenda proposed by the workshop for economic research is the most exhaustive of the four fields (this is probably a good indication that much remains to be done in this field). It was divided into four topic areas: production; utilization and demand; price analysis; and international trade and policy research.

Production. Developing practices to reduce production costs is an urgent priority; this calls for identifying the factors that restrict productivity most, both at the regional level and across regions. Constraints also need to be studied within the cropping system and within the entire farming system, with a particular focus on competition between cassava and other crops for land, labor, and cash inputs, especially fertilizers. New varieties and cultural practices need to be evaluated under farmers' conditions to provide early feedback. Their potential for cost reduction also needs to be studied. Adoption studies for new technologies are also useful in identifying constraints.

Utilization and demand. Research in this area is especially needed for planning cassava development. The importance of a valid statistical base cannot be overestimated. In countries where cassava is an important food, estimation of demand parameters is needed, together with estimations of cross-price elasticities with rice, so as to determine the role cassava might play in rice pricing policies, and consumer preference studies if novel products are envisaged. In the starch market, an evaluation of the growth in demand is completely lacking. Other important research areas are evaluation of an appropriate scale of processing and of other factors that may lead to reduced processing costs. Animal feed probably offers the most immediate prospects for cassava, and this must be a priority in demand studies; a major issue here is the role played by international grain prices vs. domestic price policies in determining the potential for cassava in this market.

Price analysis. Based on production and demand research, this would aim at determining the competitive prices of cassava in alternative markets, and would draw implications regarding farm prices and target yields. This research is of the highest priority in future planning of the crop and in generating increased government support for cassava research.

International trade and policy. International trade may at present concern relatively few countries; however, an evaluation of the potential for cassava exports in East Asia is badly needed. With regard to policy, each country needs to decide in what way cassava may contribute to government policy objectives, while in turn a definition of policy goals for cassava will have implications for both biological and utilization research priorities. Of particular significance would be a social cost-and-benefit accounting of cassava potential within the economy, with special focus on social benefits distribution and on social costs of soil erosion and of water pollution by starch factories.

CASSAVA VARIETAL IMPROVEMENT IN ASIA

During the first 10 years of the Cassava Program, CIAT had offered cassava germplasm and training/communication opportunities to Asian cassava researchers. These activities contributed to improvements and the establishment of national cassava research programs in many Asian countries. Today the majority of genetic materials handled by these national programs originated in CIAT.

A branch of the CIAT program was established in April 1983 in Bangkok, Thailand to help Asian national cassava programs utilize CIAT technology more directly. (In line with the basic policy of not doing what may be better done by national programs, CIAT's main involvement is in germplasm utilization and development, training and communication.) A breeder was located in this regional office but due to the high heterogeneity in the history of each national cassava program, the working style of the breeder varies greatly. In the Philippines, this involves helping to set up a varietal evaluation scheme virtually from scratch and being present at field selection where he works closely with young national program breeders. In Thailand and Malaysia, the CIAT breeder participates in every step of germplasm evaluation/selection. For the Indian program, CIAT provides genetic materials to enrich germplasm variability. Thorough observations on performances of CIAT germplasm in national programs provide a good appraisal of the appropriateness of germplasm already distributed and improvements to be introduced in preparing germplasm for future use.

Germplasm Distribution

Sexual seeds have been the major means of germplasm transfer, occasionally supplemented by meristem culture. During the last 10 years, more than 100,000 hybrid seeds from approximately 1,800 crosses have been distributed to cassava breeding programs in eight Asian countries (Table 1). The strategy evolved from sending any Latin American germplasm to any interested program in the early years to providing seed populations of better defined parents for the specific needs and capacity of each national program later on. It should be noted that the capacity to handle sexual seed at the national program level has increased enormously in the last few years. In many national programs, these seed populations are regarded as sources for immediate varietal selection while programs such as that in Thailand have also selected cross parents from the seed populations for their hybridization program. These materials are being processed through evaluation steps in each national program (Table 2).

Thailand

The cassava research program, with headquarters at the Rayong Field Crop Research Center, Field Crop Research Institute, Department of Agriculture, has developed a highly comprehensive varietal improvement program. More than 20,000 F_1, plants, 2,000 single-row entries, 200 replicated trial entries, 50 advanced trial entries and 20 regional trial entries are annually evaluated. Advanced yield trials are conducted in three locations, regional trials in seven sites and numerous on-farm trials in many farmers' fields. From the first CIAT seed introduction (1975), a clone selected from CM 407 cross (M Mex 55 x

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M Ven 307 crossed at CIAT in 1974) was released as Rayong 3. Starch content of Rayong 3 is much higher and its seasonal fluctuation is much less than that of Rayong 1, the leading local cultivar. The dry root yield of Rayong 3 tends to be higher than Rayong 1 under favorable conditions but under less favorable conditions with poorer soils and unpredictable rainfall, handling of Rayong 3 tends to be more delicate. Rayong 3 is currently planted on approximately 160 ha. Since fresh root yield of Rayong 3 is not significantly higher than that of Rayong 1, Rayong 3 is not expected to replace Rayong 1 on a massive scale.

Nearly 99% of the genetic materials being evaluated are either from crosses between Thai and CIAT clones, crosses between CIAT clones produced in Rayong or CIAT crosses produced at headquarters. There is a clear tendency for later generation materials (crosses made after 1980) to give better selection opportunities than the earlier materials.

One of the best selections from the earlier crosses is (CMC 76 x V 43) 21-1, a cross between a CIAT introduction and a local germplasm accession in 1978. This clone has shown a small but significant yield advantage over Rayong 1 across a wide range of environmental conditions (Figure 1). The soils on the Rayong Station are generally poor and the rainfall is unpredictable, thus, the Rayong environment represents high stress growing environments for cassava. All the initial steps of genotype evaluation/selection are concentrated in Rayong Station and (CM 76 x V 43) 21-1 was also selected there. This is encouraging not only because this confirms that the addition of CIAT-Latinamerican genetic variability contributes positively but also because this supports the traditional CIAT strategy of genetic screening under high stress conditions.

(CM 76 x V 43)21-1 may not be released ultimately because its yield advantage is only slight and its branching habit tends to give poor planting stakes. However, later selections such as OMR 23-29-15 or CMR 23-149-128 (a 1980 Rayong cross with CIAT parental material) are more promising. They have outyielded Rayong 1 by a large margin not only in Rayong but also off-station (Table 3). While there is little doubt about the higher yielding capacity of these clones over Rayong 1, more trials are needed to assess the flexibility of these clones under rugged conditions. Planting stake quality of OMR 23-29-15 taken at the beginning of rainy season is low and its root shape is not ideal. CMR 23-149-128 germinates well and produces uniform, easy to harvest roots, however, its root dry matter content is lower that that of Rayong 1. CMR 23-126-122 seems to be well adapted to high stress environments, however, its yield advantage over Rayong 1 is minimal.

These promising clones are outperforming Rayong 1 both in fresh root yield and root dry matter content when planted toward the end of rainy season and this practice is becoming more and more popular among farmers (Table 4). Some new clones gave acceptable yield at the eight month harvest (Table 5), although it is not known whether these early yields were the result of a genetically controlled early bulking habit or a result of mere high yielding capacity.

Rayong 1 is basically a high yielding cultivar adapted to commercial production by small farmers and it is because of Rayong 1 that the Thai cassava industry has been so successful. It is not easy to surpass the yield level of Rayong 1 by breeding while maintaining the agronomic flexibility of the traditional cultivar. Nevertheless, there are firm indications that many promising clones are coming through the pipeline.

Philippines

A considerable number of genetic materials have been introduced to several institutions in the past. Some of these, such as an introduction of 12 clones through the CIAT-SEARCA-IDRC project in 1978 and seed introductions by the Philippine Root Crop Research and Training Center, Visayas State College of Agriculture, Leyte, after 1982, were properly evaluated.

One of the largest cassava starch complexes in Malabang, Mindanao received the 12 clones sent in 1978 immediately after multiplication. They did their own evaluation and selected five clones for their use. Today, according to their data, these clones are planted as follows:

HMC 4	200 ha
CM 325-52	80 ha
CM 321-15	50 ha
CMC 40	40 ha
M Col 1684	10 ha

This rapid expansion of new clones replaced Hawaian 5, a selection from traditional cultivars, however, the present hectarage of each clone is more a reflection of multiplication rate rather than its level of superiority over the introduced clones. A similar case is reported from another large cassava starch complex in Leyte.

A population of 2,200 seeds from 43 crosses introduced to PRCRTC in January 1982 represented the first CIAT cassava germplasm prepared and evaluated according to CIAT's recommendations. From the F_1 seedling population, 418 plants were selected for the single-row trial from which 120 clones were further selected for a preliminary trial. From the preliminary trial, 25 clones were selected for an advanced yield trial. The yield data of these selected clones indicate a clear yield advantage (30-100%) of selected clones over local cultivars (Table 6).

From the next seed introduction to PRCRTC (5,500 seeds from 100 crosses), 819 plants were selected in the F_1, plant trial and planted in a single-row trial. The data from the single-row trial indicated that the majority of the entries outyielded a locally recommended cultivar, Golden Yellow (Figure 2). These higher yields were closely related to higher harvest index (Figure 3). From this trial, 157 clones were selected and planted for a preliminary yield trial.

Unlike Thailand, the Philippines does not have a tradition of large scale commercial production. The available local cultivars are adapted to small scale production for human consumption. They usually have good eating quality but are not particularly high yielding when planted on

larger scale for industrial use or as animal feeds, thus the advantage of selected CIAT clones for commercial production.

Malaysia

The relative importance of cassava in Malaysia is less than in the other Asian countries with which CIAT collaborates. Currently, the major production schemes are a few large scale plantations and small farmer production on illegally occupied land (both of which are mainly for starch). As in Thailand, the local cultivar Black Twigg is adapted to medium-large scale commercial production thus, it is basically a high yielding cultivar.

All CIAT seed introductions have been evaluated properly by the cassava breeding program at the Malaysian Agriculture Research and Development Institute. Selected clones from the earliest introduction (1975) have reached the final step of evaluation (repeated regional trials in productions fields) and shown some yield advantage over Black Twigg. However, their yield advantage is not great enough to massively replace this cultivar.

Selections of a later introduction (1977) seem to offer greater yield advantage (up to 60% at the 12 month harvest) (Table 7). Highly convincing yield advantage is demonstrated by the selections from 1981 and 1982; introductions which include well defined cross parents such as CM 523-7.

Indonesia

Relative to cassava's vast importance in the national economy and great diversity in production system and utilization, the national cassava research program has inadequate resources. Nevertheless, CIAT is attempting to find the best way of contributing to the small Indonesian cassava research effort.

Some selected clones from the 1975 and 1977 introductions showed a yield capacity which was much higher than that of local cultivars and equal to that of best clones selected from their own breeding program in the last 20 years. However, processing of elite materials through evaluation steps is very slow due to the limited resources allocated to cassava research.

A good part of the latest seed introduction (4600 seeds from 80 crosses, 1983) was evaluated at one of the largest cassava plantation farms in southern Sumatra as a part of cooperative project between the Bogor-based national cassava program (Central Research Institute for Food Crops) and the plantation farm. Due to fewer constraints on resources, the material was adequately processed and 574 plants were selected and planted in a single-row trial. The selected clones looked highly promising.

India

The Indian cassava research program, headquartered at Central Tuber Crops Research Institute, Trivandrum, Kerala may be the largest and most mature national cassava program in the world. Their 20 years of breeding work, based mainly on local germplasm and some introductions,

resulted in five recommended cultivars. Due to the maturity of this institution and the presence of African mosaic disease, to which the majority of CIAT germplasm is susceptible, CIAT's contribution to the Indian program has been limited largely to supplying genetic materials for germplasm enrichment and to offering training opportunities.

China

A considerable number of seeds have been introduced to the cassava breeding program at the South China Acadamy of Tropical Crops on Hainan Island. Probably due to the winter climate and high intensity of CBB, the number of clones which passed on to the second cycle of selection was small. The CIAT materials supplied were basically lowland tropical materials. How appropriate CIAT's lowland materials are for a sub-tropical climate and whether a completely different set of materials should be supplied based on subtropical parental genotypes will have to be defined.

Evaluation of Cross Parents.

Repeated observations of F_1, populations and single-row trials resulted in a general evaluation of cross parents frequently used in the CIAT hybridization scheme (Table 8). Such cross parents as CM 849-1, CM 324-170 and M Bra 12 tended to give good selection opportunities in a wide range of environmental conditions. These genotypes can be frequently used in hybridization not only as an immediate source of varietal selection but also as a carrier of specific characteristics such as disease resistances which are often only present in agronomically poor genotypes.

On the contrary, clones such as M Ven 77 and CM 517-1 were rated very low. Almost certainly all the F_1 plants coming from these cross presents will be eliminated at the first stage of evaluation (normally in the F_1 seedling trial) by national program breeders. Both M Ven 77 and CM 517-1 are known for resistance to CBB, however, the F_1 of these resistance sources crossed with agronomically better genotypes will have to be prepared to provide national programs with immediate selection opportunities.

CM 523-7, which has modest yielding capacity but high root dry matter content, good CBB resistance and reasonably good plant type, had been used with the highest frequency in CIAT hybridization during 1981 and 1982. Fortunately, CM 523-7 seems to be a reasonable cross parent for many Asian conditions.

Conclusion

After massively distributing seed materials, it should be noted that Asian programs differ in their capacity to utilize them efficiently. Thailand is evaluating and using CIAT germplasm very effectively. Although Malaysia, has a modest work scheme, it is evaluating germplasm smoothly and the Philippines has rapidly improved its capacity. Indonesia due to limited resources is struggling to achieve a scheme of germplasm evaluation and utilization that satisfies national needs. India shows little interest in CIAT germplasm in general due to its lack of mosaic resistance. China and Sri Lanka are beginning to show interest in new germplasm.

Available data already show high utility of CIAT germplasm in the Philippines, Indonesia and Malaysia. In Thailand, it was not as obvious in the beginning as had been anticipated, but good field selection during the last two years is very convincing. In India, the great majority of CIAT germplasm is susceptible to African mosaic disease, hence, the immediate usefulness of CIAT germplasm is low, however, careful selection could add new genetic variation to the hybridization program for adaptation to new areas and planting schemes. In China, CIAT must wait to see how useful the basically lowland tropical materials are for their subtropical conditions.

Table 1. CIAT cassava F_1 hybrid seeds distributed to Asian programs.

Country	Year	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	Total
Thailand		900		6170	7720		3050	1400	7450	7900	8000	42590
Indonesia		900		700						4600		6200
Philippines		900		950				5100	4700	5500	2350	19500
China									2300	6100		8400
Malaysia		900		1500			2050	1250	4050			9750
India		900		850						1050	7900	10700
Vietnam										1900		1900
Rep. China (Taiwan)		500							1200			1700
TOTAL		5000		10170	7720		5100	7750	19700	27050	18250	100740

Table 2. Evaluation of CIAT cassava materials in Asian national programs for 1984/85 (expressed in number of genotypes).

Evaluation level	Thailand[a]	Philippines	Malaysia	Indonesia	China	India
F_1 seedling	26500	2350			2500	1000
Single-row trial	2310		350	590	30	
Preliminary trial	247	223	60	20		
Advanced trial	49	35	29	20		
Regional trial	17	6	15	2		
On-farm trial	10	8				
Multiplication	1	8				
Varietal release	1	b				

[a] Including Thai x CIAT crosses produced at the Rayong Station, Thailand.

[b] Not officially recommended by the government but seven early CIAT clones are adopted by private sectors.

Table 3. Yields of some promising clones at three locations in Thailand, 1983/84.

Clone	Parents	Root dry yield (t/ha) at			
		Rayong	Banmai Samrong	Khon kaen	Average
OMR 23-29-15	CM 407-14	9.2	11.6	15.1	12.0
CMR 23-128-141	CM 407-9 x CM 309-211	6.6	8.9	13.8	9.8
CMR 23-08-8	HanateeCM 407-24	7.7	10.4	9.8	9.3
CMR 23-149-128	CM 407-24 x M Col 1684	7.6	8.6	11.5	9.2
CMR 23-17-251	Kaset x M Col 1684	8.7	5.7	10.6	8.3
CMR 23-126-122	CM 407-9 x M Col 1684	6.1	7.6	10.0	7.9
Rayong 1 (local)		5.5	6.7	10.1	7.4

Table 4. Result of off-season preliminary yield trial (selected clones) in Rayong. Planted 17 November, 1983. Harvested 6 November, 1984.

Clone	Parents	Dry yield (t/ha)	Fresh yield (t/ha)	Root dry matter content (%)	Harvest index	CBB
OMR 23-29-15	CM 407-11	18.9	45.5	41.5	.67	1.5
(V1 x R) 21-8	V1 x R1	16.4	43.3	37.9	.65	2.0
CMR 23-149-128	CM 407-24 x M Col 1684	15.4	44.0	34.6	.71	2.5
CMR 23-128-141	CM 407-9 x CM 309-211	13.7	36.6	37.4	.66	1.5
CMR 23-17-251	Kaset x M Col 1684	13.4	36.3	36.9	.59	3.5
(CMC 76 x V43) 21-1	CMC 76 x V43	13.3	30.6	43.5	.62	2.0
SMH 22-04-2	V3	12.8	34.0	37.7	.54	2.5
CRK (R1 x CMC 76) 21-235	R1 x CMC 76	12.3	36.5	33.6	.65	3.0
H.P.6	M Col 113 x M Col 22	12.0	33.0	36.4	.62	3.5
(V31 x CMC 76) 21-2	V31 x CMC 76	11.5	30.3	38.0	.57	2.5
Rayong 3	M Mex 55 x M Ven 307	10.7	27.5	39.0	.66	3.5
CMR 23-08-8	Hanatee x CM 407-24	10.4	28.5	36.4	.64	1.5
Rayong 1 (local check)		10.4	28.9	35.9	.53	3.5
29-77-5	CM 321-170 x M Mex 17	10.1	26.3	38.5	.65	3.5
66-77-7	MPTR 26 x M Ven 218	7.9	20.6	38.3	.54	2.0

Table 5. Result of standard yield trial for early harvest at the Rayong Station, harvested at eight months.

Clone	Parents	Root dry yield (t/ha)	Root fresh yield (t/ha)	Root dry matter content (%)
CMR 24-63-43	M Col 1684 x Rayong 1	9.5	27.5	34.5
CMR 23-17-156	Kaset x M Col 1684	9.4	27.7	34.1
CMR 24-14-183	CM 407-7 x Rayong 1	8.8	23.4	27.4
CMR 24-14-1308	CM 407-7 x Rayong 1	8.6	24.1	35.6
CMR 24-89-19	Rayong 1 x M Col 1684	7.7	22.9	33.5
CMR 24-87-1	Rayong 1 x CM 407-7	7.5	22.0	34.2
Rayong 3	M Mex 55 x M Ven 307	7.3	19.4	37.8
CMR 24-64-15	M Col 1684 x CM 407-7	7.1	19.9	35.8
Rayong 1 (local check)		6.6	18.9	35.1
CMR 24-23-1	CM 407-11 x Rayong 1	6.5	17.2	37.6
CMR 24-78-1	Hanatee x CM 305-15	6.0	18.1	33.0
CMR 24-43-36	CM 305-15 x M Col 1684	6.0	19.6	30.5
CMR 24-56-3	CM 309-196 x Rayong 1	5.7	17.5	32.8
CMR 24-06-19	CM 407-2 x M Col 1684	5.6	17.6	31.6

Table 6. Yield data of selected clones from preliminary yield trials at PRCRTC, Visaya State College for Agriculture, Layte. Planted 23 December, 1983. Harvested 5 September, 1984.

Clone	Parents	Dry root yield (t/ha)	Fresh root yield (t/ha)	Root dry matter content (%)	Harvest index
Trial I					
CM 3422-7	CM 630-122 x CM 728-2	19.6	61.7	31.7	.74
CM 3320-11	M Bra 12 x CM 523-7	19.4	56.7	34.3	.58
CM 3318-3	M Bra 12 x CM 342-170	18.8	59.4	31.6	.64
CM 3318-11	M Bra 12 x CM 342-170	18.4	60.0	30.6	.72
CM 3318-9	M Bra 12 x CM 342-170	18.2	58.9	30.9	.78
CM 3422-3	CM 630-122 x CM 728-2	17.7	52.8	33.6	.66
CM 323-52	M Col 22 x M Mex 59	17.7	56.1	31.6	.72
CM 3320-5	M Bra 12 x CM 523-7	16.6	46.7	35.5	.62
CM 3318-12	M Bra 12 x CM 342-170	16.5	51.7	31.9	.58
CM 3306-5	M Col 22 x CM 523-7	15.9	45.0	35.3	.65
CM 3380-11	CM 586-1 x CM 523-7	15.9	47.2	33.6	.66
CM 3318-10	M Bra 12 x CM 342-170	15.7	45.0	34.9	.67
CM 3341-4	CM 342-170 x CM 523-7	15.6	47.8	32.7	.76
CM 3341-2	CM 342-170 x CM 523-7	14.9	46.7	32.0	.74
CMC 40		14.4	47.8	30.7	.57
M Col 1684		14.3	44.4	32.3	.68
CM 3340-3	CM 342-170 x CM 586-1	13.9	45.6	30.5	.67
CM 3380-30	CM 586-1 x CM 523-7	13.1	42.8	30.7	.71
Kadabao (local)		11.6	36.7	31.6	.59
Golden Yellow (local)		8.3	27.3	30.2	.46
Trial II					
CM 3816-4	CM 1191-9 x CM 523-7	13.4	37.2	36.1	.77
CM 3745-6	CM 1105-28 x CM 728-2	13.1	35.6	36.7	.78
CM 3675-3	CM 1015-34 x CM 523-7	10.3	28.9	35.7	.73
CM 323-52	M Col 22 x M Mex 59	10.3	27.2	37.8	.75
CM 3675-4	CM 1015-34 x CM 523-7	10.2	26.7	38.2	.72
CM 3504-8	CM 728-2 x CM 523-7	9.9	25.6	38.7	.77
CM 3745-2	CM 1105-28 x CM 728-2	9.8	27.8	35.3	.74
CM 3730-5	CM 1130-7 x CM 586-1	9.8	26.1	37.4	.75
CM 3504-9	CM 728-2 x CM 523-7	9.6	27.8	34.5	.71
CM 3590-1	CM 859-12 x M Col 22	9.1	27.2	33.3	.73
Golden Yellow (local)		9.1	25.6	35.5	.77
CMC 40		8.9	24.4	36.3	.61
Kadabao (local)		8.2	24.4	33.5	.59
M Col 1684		5.5	16.1	34.1	.74

Table 7. Result of a yield trial at Jalan Kebun, Malaysia (Data source: Tan Swee Lian, MARDI).

Clone*	Starch yield (t/ha)		Fresh yield (t/ha)		Harvest index	
	9 months	12 months	9 months	12 months	9 months	12 months
CM 982-7	10.78	15.08	49.4	72.7	0.76	0.75
CM 982-2	8.18	11.66	34.1	45.5	0.53	0.52
CM 982-6	9.02	11.45	39.9	53.0	0.61	0.56
CM 942-13	9.71	11.01	39.6	45.3	0.57	0.58
CM 942-24	7.74	10.52	33.0	44.2	0.55	0.63
CM 942-28	8.88	10.43	36.1	42.0	0.64	0.60
CM 845-26	7.15	10.31	28.4	40.2	0.53	0.51
CM 892-17	8.33	10.16	33.3	40.7	0.55	0.52
CM 982-16	9.74	10.00	41.2	41.8	0.55	0.54
CM 845-31	7.26	9.75	28.5	38.8	0.49	0.52
CM 942-27	9.59	9.74	41.5	44.6	0.55	0.57
Black Twig	9.27	9.30	39.5	41.1	0.57	0.55
CM 982-3	5.79	9.15	25.6	39.5	0.49	0.55
CM 942-18	9.75	9.13	41.9	43.9	0.58	0.54
CM 942-25	6.47	9.06	28.3	38.5	0.59	0.59
CM 892-15	8.01	8.94	32.5	38.2	0.63	0.62
CM 982-39	6.61	8.85	27.4	37.8	0.45	0.45
C5	6.62	8.19	28.0	35.2	0.54	0.55
CM 982-4	5.76	8.00	24.4	34.8	0.42	0.47
CM 892-16	8.10	8.00	32.7	33.0	0.53	0.51
CM 942-33	7.10	7.79	29.4	34.5	0.49	0.49
CM 942-4	7.30	7.72	32.4	34.7	0.53	0.54
CM 845-23	5.69	7.05	22.2	27.8	0.48	0.48
CM 942-19	7.27	6.94	31.5	31.3	0.55	0.51
CM 942-21	6.13	6.92	25.6	28.6	0.54	0.53
CM 942-30	6.15	6.53	25.3	28.6	0.44	0.45
CM 892-10	5.64	6.51	23.0	27.2	0.42	0.47

* CM 845: M Ven 270 x M Col 1684, CM 892: M Mex 17 x M Col 1684
CM 942: CM 307-37 x M Col 1684, CM 982: CM 321-170 x M Col 1684.

Table 8. Evaluation of cross parents.[a]

Cross parent	Average score at[b] Rayong, Thailand	Leyte, Philippines	Lampung, Indonesia	Total Average
CM 849-1	4.38	3.72	4.09	4.06
CM 342-170	4.67	3.61	3.48	3.92
M Bra 12	4.40	3.40	3.85	3.88
CM 523-7	4.13	2.72	4.75	3.86
CM 727-38		3.01	4.50	3.75
CM 681-2	3.83	3.17	4.11	3.70
CM 1015-42		3.40	4.00	3.70
CM 586-1	4.30	3.05		3.68
CM 922-2	3.80	3.67	3.53	3.67
CM 1015-19		3.94	3.33	3.63
M Col 1684	3.36	3.04	4.50	3.63
CM 728-2		3.50	3.80	3.61
CM 1015-34	4.00	3.43	3.20	3.54
M Col 22	3.66	3.23	3.33	3.41
CM 91-3	3.00	3.22	3.83	3.35
CM 727-14	4.00	2.59		3.29
CM 950-3		3.55	3.00	3.28
M Pan 51		3.20	3.33	3.26
Rayong 1	3.20			3.20
M CR 2	2.67	3.01		2.81
M Ven 131	2.80	2.56		2.68
CM 517-1	2.80	2.12		2.46
M Ven 77	1.67	1.80		1.74
Hanatee	1.67			1.67

[a] F_1 plants were evaluated for general yield performance at harvest by cross at each location. Average score for cross parent at each location was obtained by averaging more than four crosses which included the same parent.

[b] Scale: 1: poor; 5: excellent.

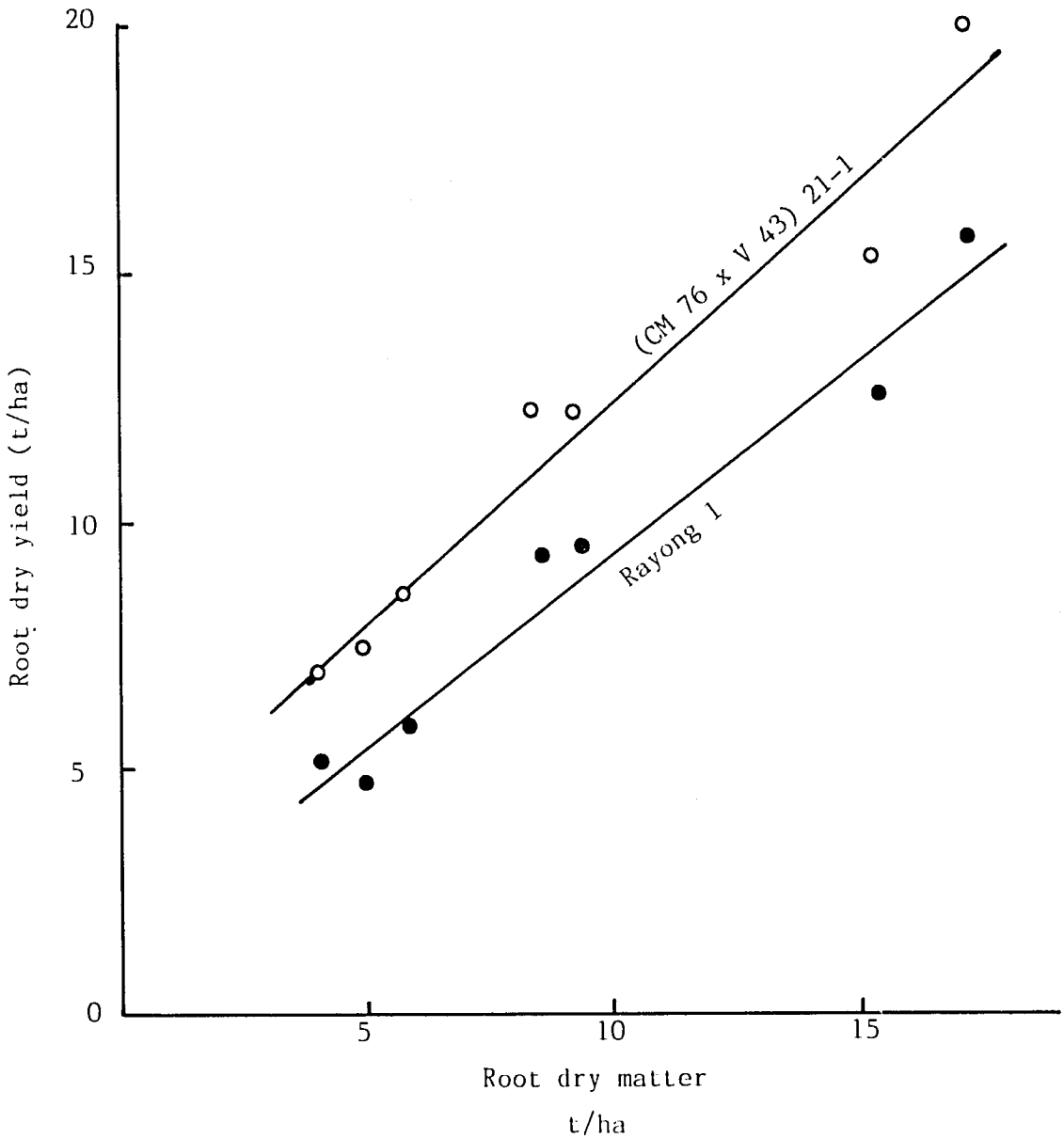


Figure 1. Productivity of Rayong 1 and promising selection under different levels of productivity. Productivity of environment (expressed as average yield of all entries in each trial).

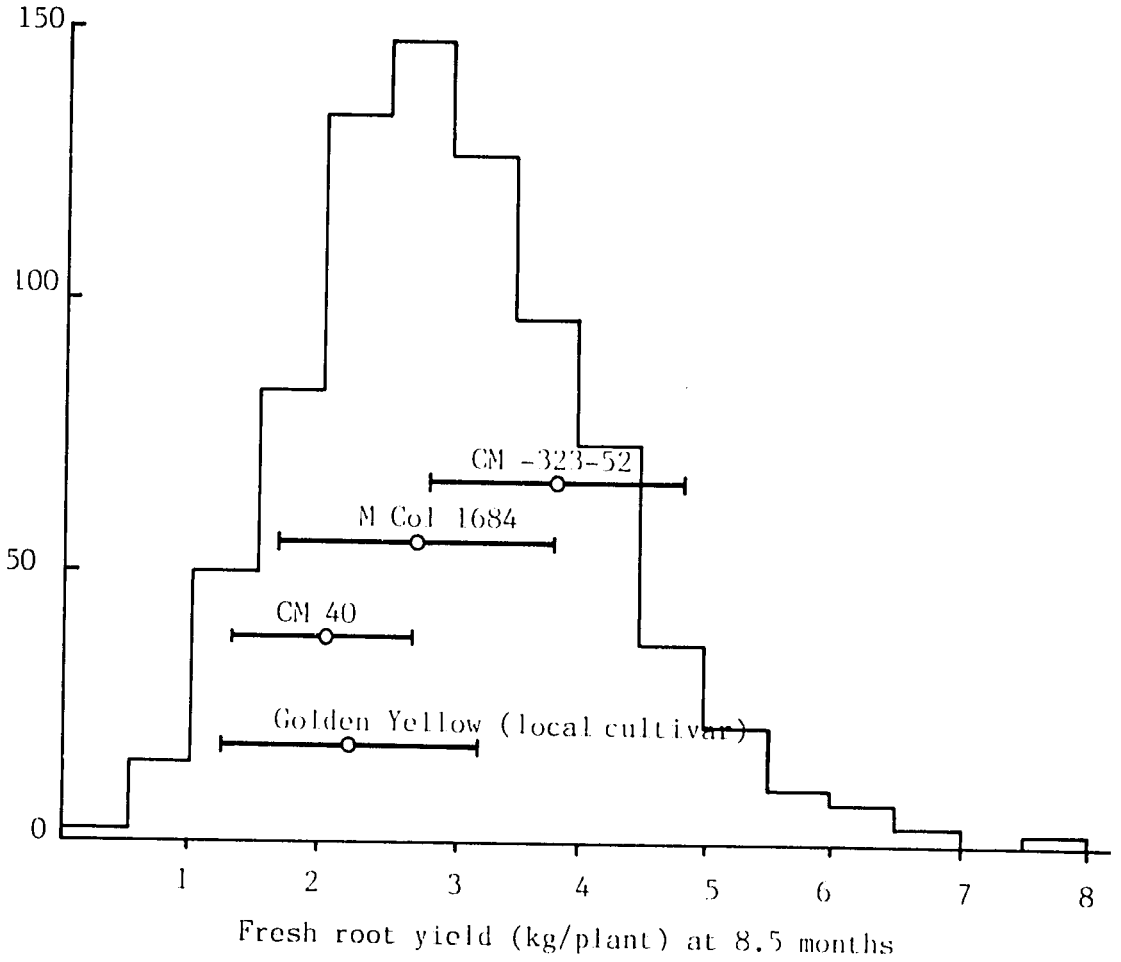


Figure 2. Frequency distribution of root yield of all clones evaluated in single-row trial, PRCRTC 1983/1984.

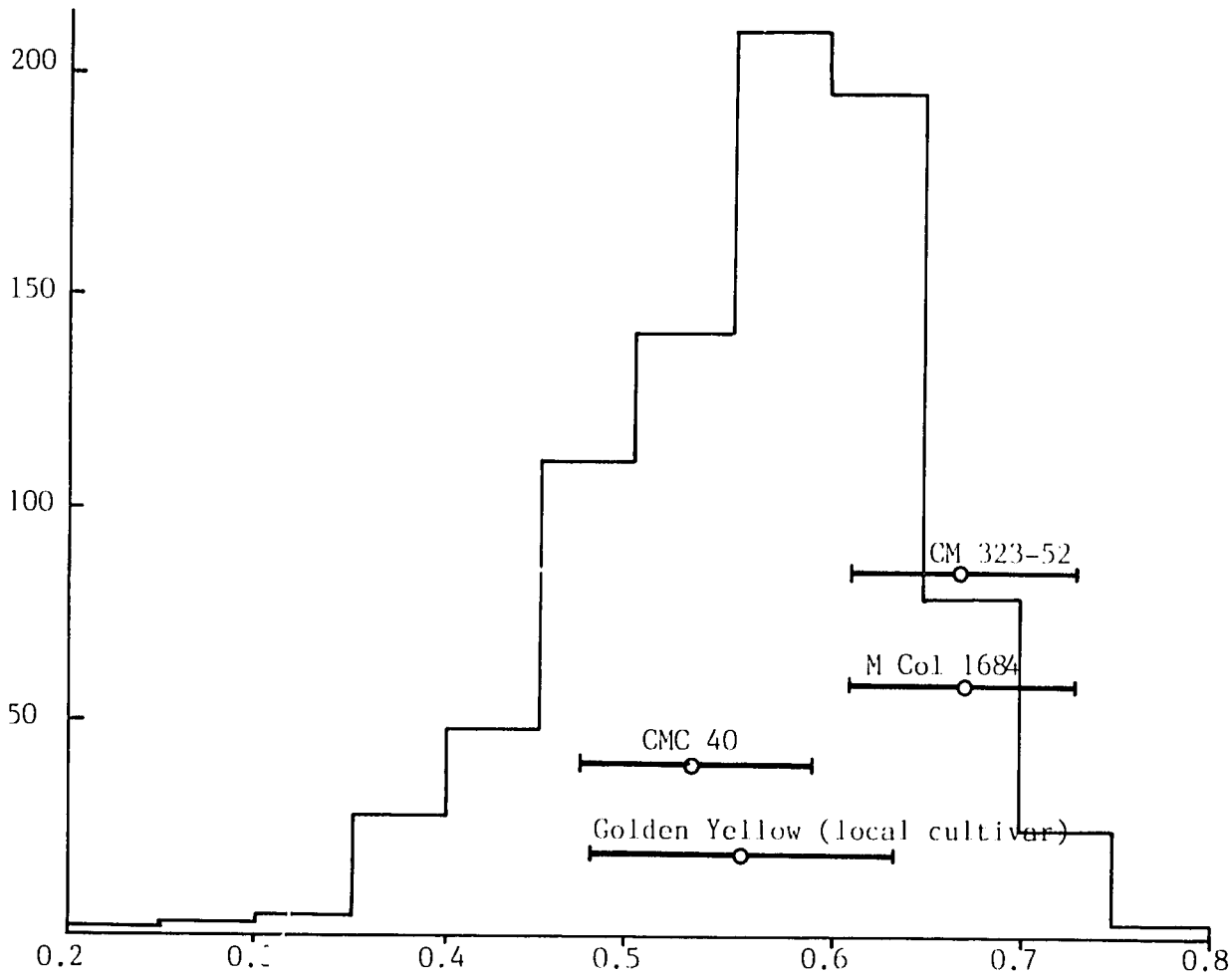


Figure 3. Frequency distribution of harvest index of all clones evaluated in single-row trial, PRCRTC 1983-84.

I. Plant Types for Water Stress Conditions

In the Cassava Annual Report (1980) it was suggested that "..... when stress occurs in the middle of the growth period a vigorous variety may be preferable to a less vigorous type which may yield better under non-stress conditions". In the trials that led to this conclusion it was not possible to ascertain whether a single plant type could yield well under stress and non-stress conditions. This year the physiology section turned to this problem.

The hypothesis is shown in Figure 1. A variety with slightly more than the optimal Leaf Area Index (LAI) will reduce its LAI under stress with minimal effect on yield while an optimal plant type for non-stress conditions will yield only very slightly more under these conditions but will be very sensitive to stress. On the other hand, an excessively vigorous variety will produce less under optimal conditions than under stress. Hence, it would appear that for stable high yield over stress and non-stress conditions a variety with above optimal leafiness under good conditions is required. Results from trials at the Quilichao station confirm this hypothesis.

M Col 1684, a high yielding, moderately vigorous clone, was compared with the leafier CM 507-37 (a cross between M Col 1684 and M Col 1438). On some plots water was withheld from the soil by covering it with white plastic sheet. In the non-stressed plots CM 507-37 reached LAIs of close to five which are above the optimum while M Col 1684 scarcely reached the optimum levels of 2.5-3.5. In the later growth stages LAI of both varieties was less than optimal with very low levels in M Col 1684 (Figure 2). The fresh and dry root yields reflect these trends (figures 3 and 4). Maximum root growth rates occurred when LAIs were between 2-5. When the LAI of M Col 1684 dropped in the last 100 days, root filling essentially ceased. CM 507-37 maintained an LAI of about 1.5 in this period and substantially outyielded M Col 1684 as a result. The question still remains as to why the early yield (e.g. at six months after planting) of CM 507-37 with an above optimum LAI was equal to that of CM Col 1684. The Leaf Area Ratio (LAR) (calculated only for the above-ground portions of the plant) in CM 507-37 was greater than that of M Col 1684 (Figure 5). This indicates that CM 507-37 uses dry matter in the aerial portion of the plant more effectively for producing leaves than M Col 1684, resulting in a higher optimal LAI. This is presumably related to smaller nodes and internodes per unit leaf area and this point merits further research.

In the stressed plots LAI was reduced in both varieties (Figure 2). CM 507-37, however, maintained a higher LAI. Furthermore, CM 507-37 produced a flush of new leaves in the recovery period and maintained a higher LAI than M Col 1684. The higher LAI of CM 507-37 resulted in higher yields (Figures 3 and 4). The yield reduction in M Col 1684 was small due to the large increase of LAI, compared with the control, in the recovery period. Nevertheless, the yield was less than that of CM 507-37.

The paramount importance of LAI in determining yield even when a long stress period occurs is shown in Figure 6. The yield of four cultivars, different in their vigor and grown under non-stress and mid-term stress conditions in two separate trials, is closely associated with the average LAI during the growing cycle. (The LAI is a characteristic of the genotype and also is highly dependent on water conditions). The highest reference (100%) yields in both trials were 19 t dry root/ha^{-1} for CM 507-37 under non-stress conditions over 345 days (Experiment I) and 11.2 t ha^{-1} for M Col 22 under non-stress conditions over 306 days (Experiment II). (55 Kg ha^{-1} day^{-1} and 37 Kg ha^{-1} day^{-1}, respectively). The performance of these cultivars conform with the suggested hypothesis.

In conclusion, it can be stated that high yield under mid-term stress conditions is not incompatible with high yield under non-stress conditions. The high yield levels (e.g. CM 507-37) under both conditions (19 and 16 t dry root/ha in less than one year) can be obtained by having slightly higher than optimal LAI under non-stress conditions.

II. Water Relation

A. Effect of humidity and wind on leaf conductance of cassava grown in Carimagua.

In cooperation with the cassava nutrition section an experiment was conducted to investigate the response of cassava to irrigation and fertilizer application at the Carimagua experiment station. The cassava cultivar M Ven 77 was used as testing material and planted on the 1st of November 1983. Throughout October and November, natural rainfall was abundant (177 mm and 114 mm, respectively) and soil water content in the upper two meters was determined one month after planting (on December 2, 1983) by taking soil samples at various intervals with a hand-driven soil auger. Table 1 contains data of the soil water content along with the characteristic range of available percentage of water for the Carimagua soil between soil water potentials of -0.03 and -1.5 MPa. The data clearly demonstrate that, at that time, the soil was uniformly wet with its water content near the field capacity in the upper layer and with excess water in the lower layers.

The abaxial leaf conductance was measured on the same day when the sky was clear at 10:00 to 11:00 h and 13:00 to 14:00 h with a humidity sensing diffusion porometer. Measurements were made on young fully expanded leaves (YFEL) from all plots and the water potential of the same leaves was determined by the pressure chamber technique. The abaxial leaf conductance as a function of leaf to air vapor pressure difference (VPD) is illustrated in Figure 7. Leaf conductance decreased with increased VPD from the late morning to the midday under bright sunlight. The very highly significant correlation coefficient ($r = -0.815$, $P = 0.001$) indicate that the stomata reacted by partially closing with increased VPD. The bulk leaf water potential of the same leaves remained practically constant in the two periods of measurement (were -1.3 ± 0.2 and -1.4 ± 0.2 M Pa for late morning and midday, respectively). The leaf temperature, also, remained relatively unchanged (32.5 ± 0.9 and 33.4 ± 0.8 °C, in late morning and midday measurements). The ambient relative humidity decreased from 68% in the

late morning to 54% at midday. It appears, therefore, that the factor responsible for the changes in leaf conductance was the leaf-air VPD which varied from 1.4 to 2.6 kPa.

The calculated abaxial transpiration rate decreased with increased VPD (Figure 8). The highly significant negative correlation coefficient ($r = -0.637$, $P = 0.001$) between transpiration and VPD suggests that the reduction in stomatal conductance was large enough to offset the increase in VPD and cause further reduction in transpiration. These results, therefore, confirm the previous reports (e.g. Cassava annual reports, 1982, 1983) on the sensitivity of stomata of various cassava cultivars to VPD observed with controlled laboratory experiments.

On December 6, 1983, and at midday (12:00 to 13:00 h) when the sky was clear and a northeast wind was blowing at an average velocity of 4 m s^{-1} at 2 m height, as indicated by the nearby weather station, abaxial leaf conductances were measured on leaves facing the wind (up-wind direction) and on leaves (on the same plants) away from the wind (downwind direction). Leaves facing the blowing wind (upwind direction) showed extremely low conductances (0.65 ± 0.28 mm s^{-1}) (Table 2). On the other hand, leaves on the opposite side of the same plants (down-wind direction) had much higher conductances (3.34 ± 1.0 mm s^{-1}). These results indicate that the leaves most exposed to wind almost completely closed their stomata; whereas the least exposed leaves maintained their stomata partially opened.

The concept that stomata of cassava react directly to changes in humidity and independently of bulk leaf water potential is further supported by the present field data. The role of wind can further intensify the reaction of stomata to changes in humidity. The almost complete stomatal closure observed in the present study with the upwind leaves could be explained by the possible reduction in the thickness of the moist boundary layer adjacent to the leaf surface, through the action of wind, and therefore much drier air gets in close contact with the stomatal apparatus.

B. Stomatal response to air humidity and its relation to stomatal density in cassava and in a wide range of warm climate species.

In view of the overwhelming evidence that cassava stomata are highly sensitive to changes in atmospheric humidity irrespective of the plant-soil water status and the fact that this may or may not be advantageous for productivity depending on soil water conditions, the mechanism and the plant characters associated with this response were investigated. A series of trials were conducted to observe the effects of changing humidity on leaf conductance of a wide range of species, under controlled laboratory conditions, to elucidate the mechanisms involved in the responses and the role the stomatal density might have in these mechanisms.

Table 3 summarizes data of the apparent photosynthetic rates (P_A), leaf conductance to water vapor as a function of VPD along with the stomatal characteristics of various species. All species showed a decrease in P_A and leaf conductance as VPD increased. The percentage reduction in P_A and leaf conductance varied among species with beans

showing the lowest reduction (25%) and cassava the highest (85%). The reductions in P_A were highly correlated with reductions in conductance among species ($r = 0.926$, $P = 0.001$) (Figure 9). The absolute decrease in leaf conductance per unit change in VPD was greatest in those species which showed a greater conductance at low VPD (Figure 10, $r = 0.905$, $P = 0.001$).

The species also varied in stomatal density (weighted for their relative distribution on the upper and lower surfaces of the leaf). There was a seven-fold difference in the weighted stomatal density (WSD) among species with maize possessing the lowest density (81 stoma mm^{-2}) and rice having the highest density (559 stoma mm^{-2}). The relative reduction in both P_A and conductance was very highly correlated with WSD ($r = 0.753$, $P = 0.001$ for P_A and $r = 0.717$, $P = 0.001$ for conductance). This relationship is illustrated for P_A and WSD in Figure 11. Furthermore, when cassava leaves were exposed to cycles of dry and humid air, P_A increased on exposure to dry air and then decreased (Figure 12). On exposure to humid air P_A showed a rapid decline and then increased.

These data suggest that the degree of stomatal sensitivity to changes in humidity is associated with both maximum stomatal conductance and stomatal density. It is assumed that an increase in either of these factors (i.e. maximum conductance and stomatal density) would be expected to be associated with increased peristomatal evaporation. This might explain the rapid decline in transpiration observed with the most sensitive species such as cassava as compared to less sensitive species such as maize (Figure 13). Peristomatal evaporation, could lead to localized dehydration of the stomatal apparatus and the adjacent epidermal cells with no observable effect on bulk leaf water potential. Furthermore, the rapid transient response to changes in humidity observed with cassava (Figure 12) as well as some other species can only occur if the epidermis is poorly connected with the large buffering capacity of the mesophyll. This reasoning then indicates: (a) that the hydraulic resistance between the epidermis and the mesophyll is large; and (b) that the conductivity between the stomatal apparatus and the adjacent epidermal cells is high. Based on this hypothesis, one should expect the epidermal water potential to approach that of the guard cells and the decrease in epidermal water potential will depend on the overall water loss of all guard cells. Thus, the greater the weighted stomatal density (the WSD is referred to as the "crowding" index) on the surface of the leaf the greater will be the decrease in epidermal water potential, with a concommitant decrease in turgor of the stomatal cells and greater closure. It is, then, concluded that the relative stomatal sensitivity to humidity should be closely related to the crowding index and this was indeed the case as observed in the present study (Figure 11).

The photosynthetic rate of C-3 species surveyed in the present studies, including cassava, showed a marked positive correlation with maximum conductance (Figure 14). This indicates that maximum photosynthesis will be associated with high stomatal sensitivity to humidity. In the case of crops grown with nonlimiting soil water, this association between maximum P_A and stomatal sensitivity will be disadvantageous for maximizing productivity. However, the probable

solution for this dilemma might be found in a leaf model with stomata uniformly distributed on both surfaces (amphistomatus leaves). A hypostomatus leaf, other factors being equal, with a given stomatal density on one surface will have the same total conductance as an amphistomatus leaf with half the stomatal density on both sides of the leaf. The crowding index of an amphistomatus leaf will, however, be half that of a hypostomatus leaf and hence, the former will be relatively less sensitive to changes in humidity but will also have high conductance and hence high photosynthetic rate. In a similar manner, it could also be argued that crop plants grown under limited soil water supply with prolonged periods of atmospheric stress should have a high stomatal density on both sides of the leaf, thus making them both sensitive to large VPD and also possessing a high photosynthetic capacity. Under these conditions however water use efficiency is maximized by stomatal opening only during the period when light intensity is low and the VPD small when maximization of leaf conductance is not critical.

Conclusions on Cassava Reaction to Water Stress.

In previous annual reports it has been shown that cassava reacts to reduced soil water availability by reducing LAI and hence potential transpiration. In addition, the stomatal closure when leaf to air VPD is large reduces transpiration when potential evapotranspiration is large; this results in water use efficiency (WUE) values in cassava that are closer to those of C-4 than C-3 plants. Because of the very high harvest indices found in stressed cassava plants the WUE in terms of economic yield are much higher than in most crop species including the C-4 plants. Maximizing WUE is an essential feature for adaptation to conditions where soil water is limiting for prolonged periods in the growth cycle.

It should, however, be noted that the same mechanism, stomatal sensitivity to changes in VPD, will reduce potential crop productivity when soil water is not limiting. For these conditions less sensitive varieties could be advantageous. It has already been suggested that less sensitivity could be expected from amphistomatous leaves due to reduced crowding index. Amphistomatous leaves (30% of stomata on the upper surface) have been identified in some cassava clones and hence the potential exists for selection for less sensitivity. Selection for parental material could be done relatively rapidly with diffusion porometers and field microscopes that are commercially available.

In the field trials, artificial misting has been used to increase photosynthesis and hence the growth rate of roots. This is not a practical proposition for low input agriculture. However, the data show that increasing air humidity and also decreasing windspeed are potentially advantageous. This view is supported by data showing that under hot humid conditions with low wind speed in the Valley of Patia in southern Colombia, yields of 15 t/ha fresh roots in four months have been obtained. In those areas where natural conditions are not so favorable it should be possible to increase productivity by mixed cropping with species that act as wind breaks and increase humidity during the wet season through their transpiration.

In the future, when assessing the potential of an area for increased cassava production it would be wise to pay careful attention to the air humidity of the zone. Zones which in the past have not been considered suitable due to low rainfall may in fact be appropriate for cassava production if air humidity is high.

III. Viruses

Cassava viruses can cause severe yield losses. However, the effects of some on yield are unknown and the mechanisms by which yield is decreased in others have not been investigated. The effects of three virus diseases: latent, caribbean mosaic and frog skin on photosynthesis were studied in detail. Frogskin diseased plants have no visible symptoms on aerial parts of the plant but roots show a thickened cortex and fail to thicken or deposit starch in large quantities. Caribbean mosaic disease manifests itself as a mosaic of chlorotic patches on the leaf and also leaf distortion. The disease symptoms disappear when temperatures are high (daytime temperatures above 31 ^{o}C). Latent virus causes no obvious disease symptoms in most infected cultivars, however the clone Secundina which is used as an indicator shows mosaic symptoms when infected.

Latent virus-infected and clean plants of M Col 22 were grown in large pots. No disease symptoms were observed on the plants and chlorophyll content for M Col 22 was not altered (approx 4.5 mg chlorophyll/g fresh leaf). Photosynthesis was, however, significantly reduced 18% from 29.8 to 24.4 mg CO_2 dm^{-2} leaf hr^{-1}. The decrease in photosynthesis was related to an increase of 29% in the internal resistance to CO_2 suggesting a direct effect of the virus on the biochemistry of photosynthesis. The 18% reduction in photosynthesis, even in plants with no visible symptoms, suggests that latent virus may cause severe yield reductions and should be more carefully researched.

Plants with frog skin disease also showed a marked reduction in net photosynthesis from 26.8 mg CO_2 dm^{-2} hr^{-1} to 13.0 mg CO_2 dm^{-2} hr^{-1}. When leaf clipping (either 50% or reducing to one leaf per plant) was practiced two days before measuring photosynthesis the differences disappeared (Table 4.). This suggests that the reduced size of the root sink in infected plants has a feedback effect reducing photosynthesis which is removed when the relative size of the source (the leaves) to the sink is reduced. This hypothesis is supported by the increase in internal resistance of infected plants with their full leave complement from 5.1 to 9.6 s cm^{-1}. This increase is indicative of a decrease in photosynthetic capacity at the cell level which would be expected in the case of a feedback effect. Thus, it can be concluded that frog skin disease has no direct effect on the photosynthetic capacity of the leaves and yield reductions are caused by a limitation either in the translocation of carbohydrates to the roots or their inability to accept carbohydrates.

Plants infected with Caribbean mosaic virus but with no visible symptoms of the disease showed no significant reduction in net photosynthesis. In plants with mosaic symptoms, photosynthesis was reduced from 26.0 to 21.2 mg CO_2 dm^{-2} hr^{-1} (Table 5). The decrease was related to a marked increase in stomatal resistance with no change in

internal CO_2 resistance (Table 5). This indicates that the chlorosis did not reduce chlorophyll levels sufficiently (from 4.14 to 3.76 mg chlorophyll/g fresh leaf) to reduce photosynthesis as this would be reflected in an increase in internal resistance. This also suggests that for cassava in general, chlorophyll content is above critical levels for optimal photosynthesis. The results obtained indicate that under those growing conditions where symptoms occur, Caribbean mosaic virus will reduce cassava yields through reduced photosynthesis but when symptoms are not apparent yield will not be significantly decreased by the presence of the virus.

Table 1. Soil water content as measured on December 2, 1983, at the experimental site, Carimagua experimental station.

Soil depth cm	% moisture (volume)	% moisture at -0.03 MPa	% moisture at -1.5 MPa
0 - 20	31.8	31.8	15.4
20 - 60	36.1	31.2	12.1
60 - 100	39.6	35.6	12.4
100 - 120	42.3	35.2	13.9
120 - 160	47.3	31.0	16.2
160 - 200	45.9	30.5	17.6

Source: Estudio semidetallado de los suelos del Centro Nacional de Investigaciones Agropecuarias de Carimagua (ICA-CIAT). 1983. Ministerio de Hacienda y Credito Publico. Bogota, D.E., Republica de Colombia, S. America.

Table 2. Leaf temperature and leaf diffusive conductance to water vapor as affected by wind. Measurements were made at midday (12:00 - 13:00 h) on December 6, 1983 at the Carimagua experimental station. Air temperature: 32.5°C; relative humidity 64%; bright sunlight.

Leaf	Upwind direction		Downwind direction	
	T°C	Conductance mm s^{-1}	T°C	Conductance mm s^{-1}
1	33.4	1.4	33.5	4.0
2	32.7	0.7	33.5	2.6
3	32.9	0.5	33.6	3.8
4	32.8	0.6	33.6	2.8
5	32.7	1.3	33.5	3.6
6	32.6	0.5	33.4	2.6
7	32.5	0.8	33.4	2.
8	33.2	0.6	33.2	2.7
9	33.1	0.5	33.6	5.6
10	33.2	0.5	33.5	3.2
11	33.1	0.5	33.4	5.0
12	33.2	0.5	33.4	3.2
13	33.2	0.4	33.1	3.4
14	33.2	0.8	33.1	4.8
15	33.2	0.4	33.1	2.7
16	33.2	0.7	33.1	3.4
17	33.1	0.6	33.1	2.6
18	32.4	0.5	33.1	1.8
Mean ± s.d.	33.0 ± 0.3	0.65 ± 0.28	33.4 ± 0.2	3.34 ± 1.0

Table 3. Apparent photosynthetic rate (P_A), leaf conductance as affected by leaf-air VPD, and stomatal characteristics among a wide range of C_4 and C_3 warm climate species.

Species	Apparent photosynthetic rate at 1 to 1.5 kPa VPD	Leaf conductance to water vapor at 1 to 1.5 kPa VPD	Reduction in P_A at 3.5 to 4.5 kPa VPD	Reduction in conductance at 3.5 to 4.5 kPa VPD	Weighted stomatal density (WSD)	Weighted[b] relative stomatal area (WRSA)
C_4	mol CO_2 $m^{-2}s^{-1}$	mm s^{-1}	%	%	stoma mm^{-2}	%
1- Grain sorghum	41.2 ± 2.6[a]	4.8 ± 0.9[a]	41	45	113	7.7
2- Maize	41.0 ± 1.3	4.2 ± 0.3	30	33	81	2.5
3- Andropogon	46.8 ± 3.2	7.0 ± 1.7	40	52	117	10.9
C_3						
4- Eucalyptus	21.3 ± 2.3	4.4 ± 0.4	55	53	548	15.6
5- Mandarin	12.2 ± 1.1	3.8 ± 0.5	56	69	489	23.2
6- Swinglea	14.4 ± 1.7	4.7 ± 0.7	61	54	310	15.7
7- Papaya	19.2 ± 1.0	3.5 ± 0.3	48	47	404	20.2
8- Cotton	21.0 ± 1.5	3.7 ± 0.5	38	41	155	10.9
9- Cassava	24.7 ± 0.9	6.2 ± 0.9	85	86	474	12.5
10- Cowpea	23.0 ± 5.4	4.9 ± 0.9	42	41	154	5.4
11- Bean	22.4 ± 1.5	4.5 ± 0.5	25	25	233	9.7
12- Mungbean	29.4 ± 1.3	4.3 ± 0.4	34	34	249	10.3
13- Seed peanut	27.5 ± 1.4	5.4 ± 0.6	43	43	122	5.1
14- Forage arachis	29.2 ± 1.5	6.6 ± 1.1	47	45	100	4.0
15- Siratro	24.6 ± 1.8	6.9 ± 1.3	64	78	523	21.3
16- Watermelon	26.8 ± 0.9	5.7 ± 0.4	51	59	276	16.2
17- Squash	17.4 ± 0.7	3.2 ± 0.3	50	50	363	20.4
18- Tomato	27.7 ± 1.2	5.7 ± 0.8	33	32	142	11.4
19- Rice	29.9 ± 2.7	7.0 ± 1.2	72	65	559	8.2

a Values are means ± s.d.
b Guard cells are included.

Table 4. Effects of frog skin disease and leaf clipping on photosynthesis and related parameters of the variety QPR.

	Treatment					
	No clipping		50% leaf clipping		All leaves except one removed	
	Control	Infected	Control	Infected	Control	Infected
Photosynthesis (mg dm^{-2} h^{-1})	27	13**	32	30	32	29
Leaf resistance [a] (s cm^{-1})	4.5	5.6	3.4	3.1	3.8	2.9
Internal resistance[a] (s cm^{-1})	5.1	9.6*	6.3	4.7	4.0	4.40

[a] Leaf resistance to water vapor; internal resistance to CO_2.

* Significant difference at P = 0.05 between infected and control in that treatment.

** As above but P = 0.01.

Table 5. Effect of Caribbean mosaic on photosynthesis and related parameters.

	Photosynthesis ($mg\ CO_2\ dm^{-2}\ h^{-1}$)	Leaf resistance to water vapor ($S\ cm^{-1}$)	Internal resistance to CO_2 ($s\ cm^{-1}$)
Control	26	3.6	5.3
Infected plants with mosaic symptoms	21**	4.7*	5.3
Control	32	2.9	5.9
Infected plants with no symptoms	28	3.2	4.7

* Significant difference between control and infected plants at P = 0.05 of the Duncan Multiple Range Test.

** Significant different between control and infected plants at P = 0.01.

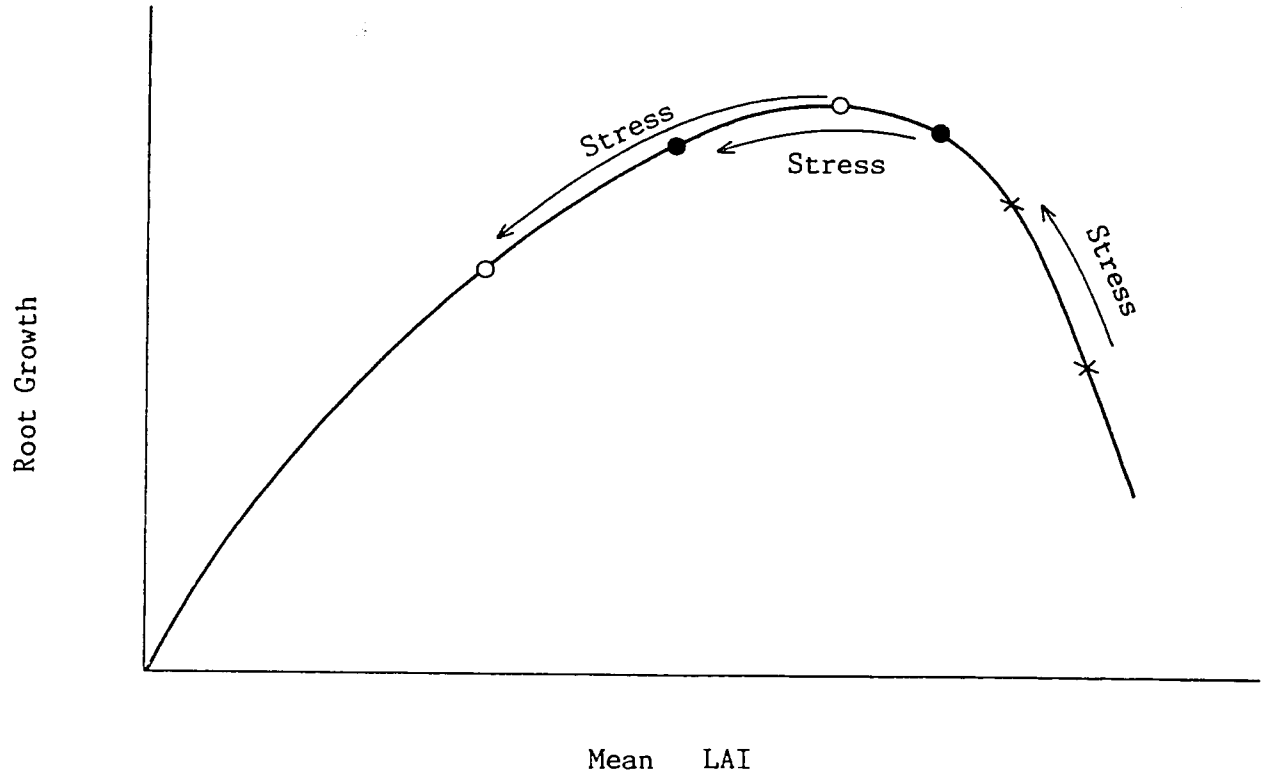


Fig. 1. Schematic diagram of how a variety can be obtained with good yield under stress and non-stress conditions. (O ideal plant type, ideal conditions; ● ideal plant for mid-term stress; x excessively vigorous type).

Fig. 2. Leaf Area Index (LAI) as a function of time after planting under non-stress and mid-term water stress conditions for the hybrid CM 507-37 and the parent M Col 1684.

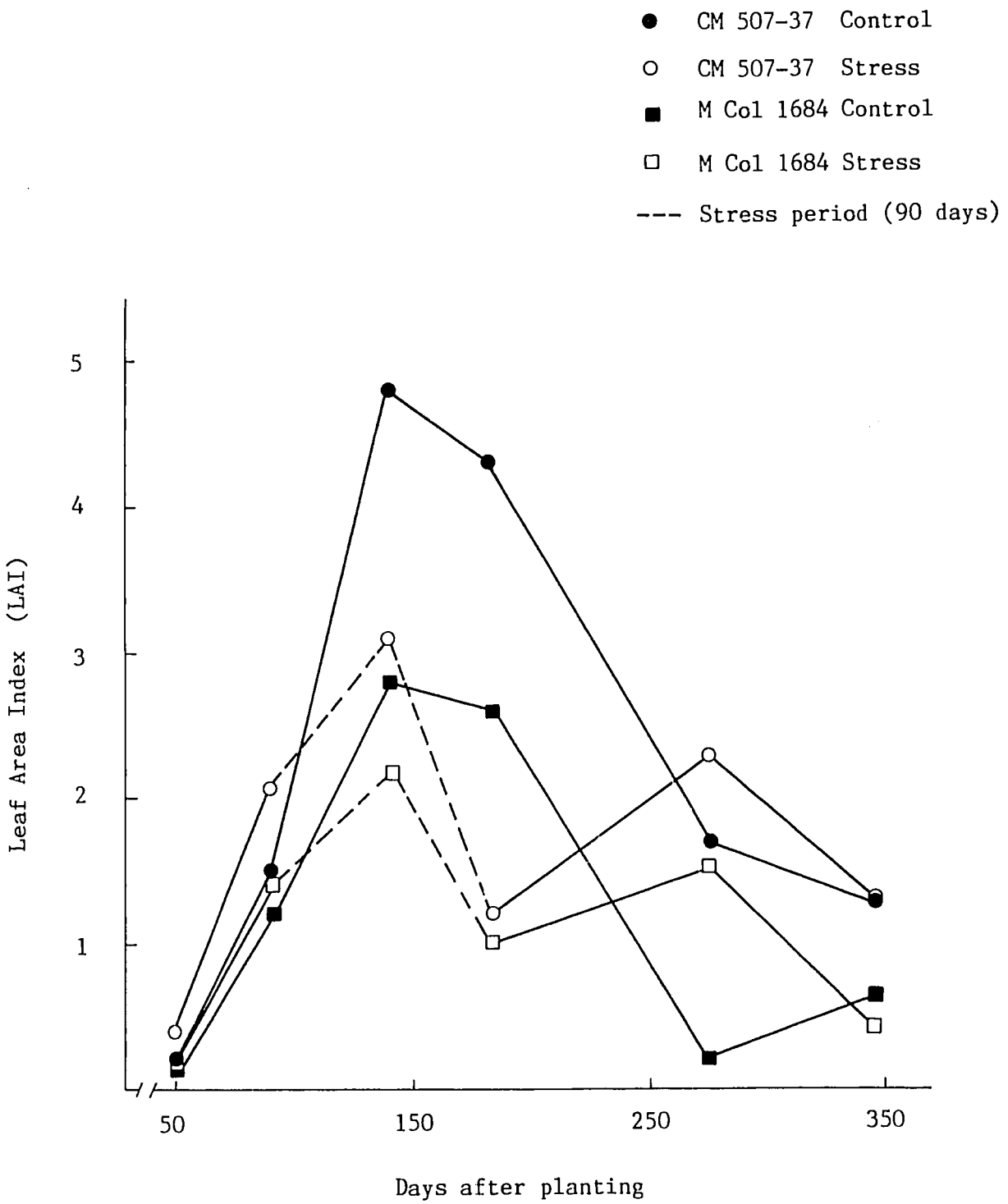


Fig. 3. Fresh root yield as a function of time after planting under non-stress and mid-term water stress conditions for the hybrid CM 507-37 and the parent M Col 1684.

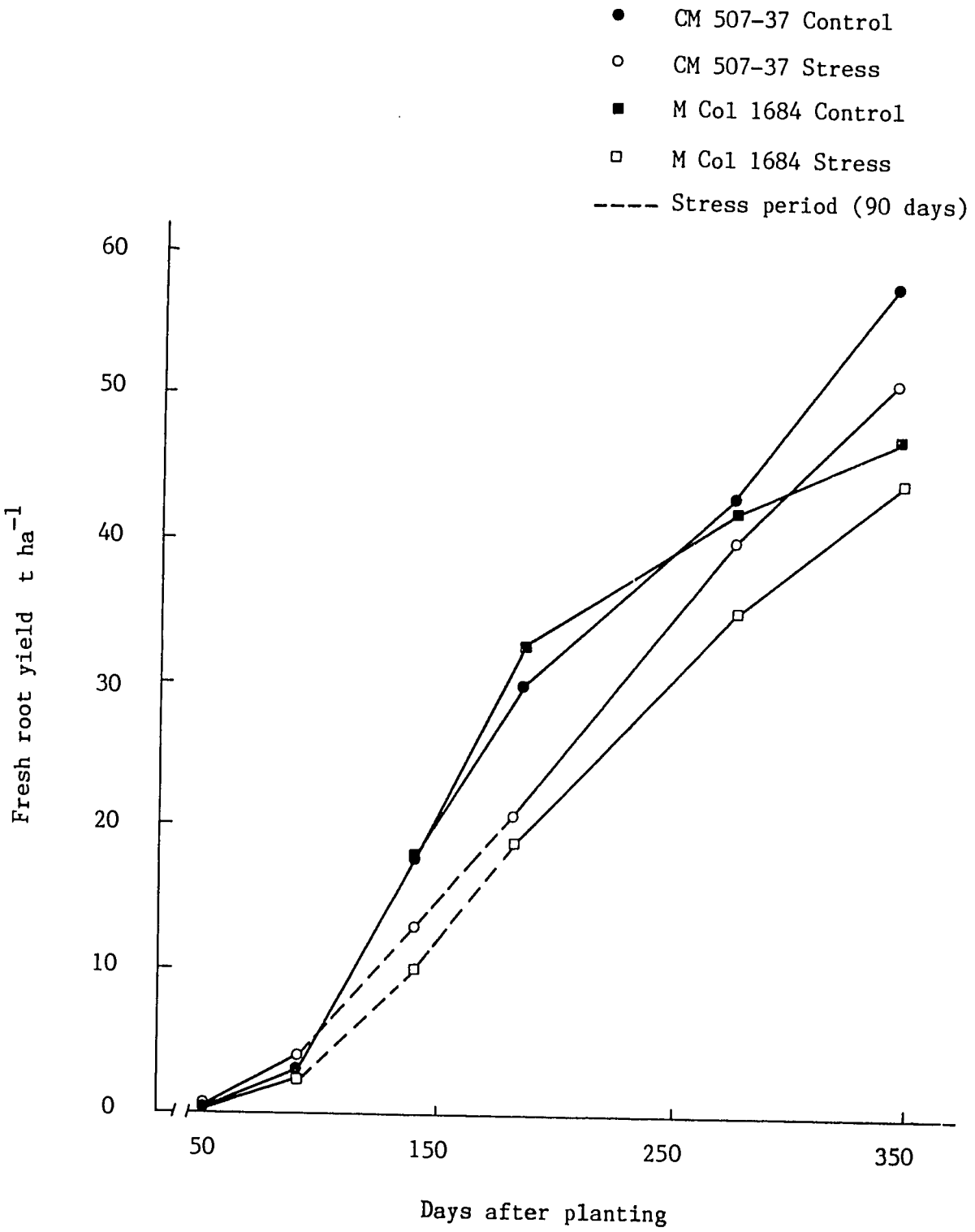


Fig. 4. Dry root yield as a function of time after planting under non-stress and mid-term water stress conditions.

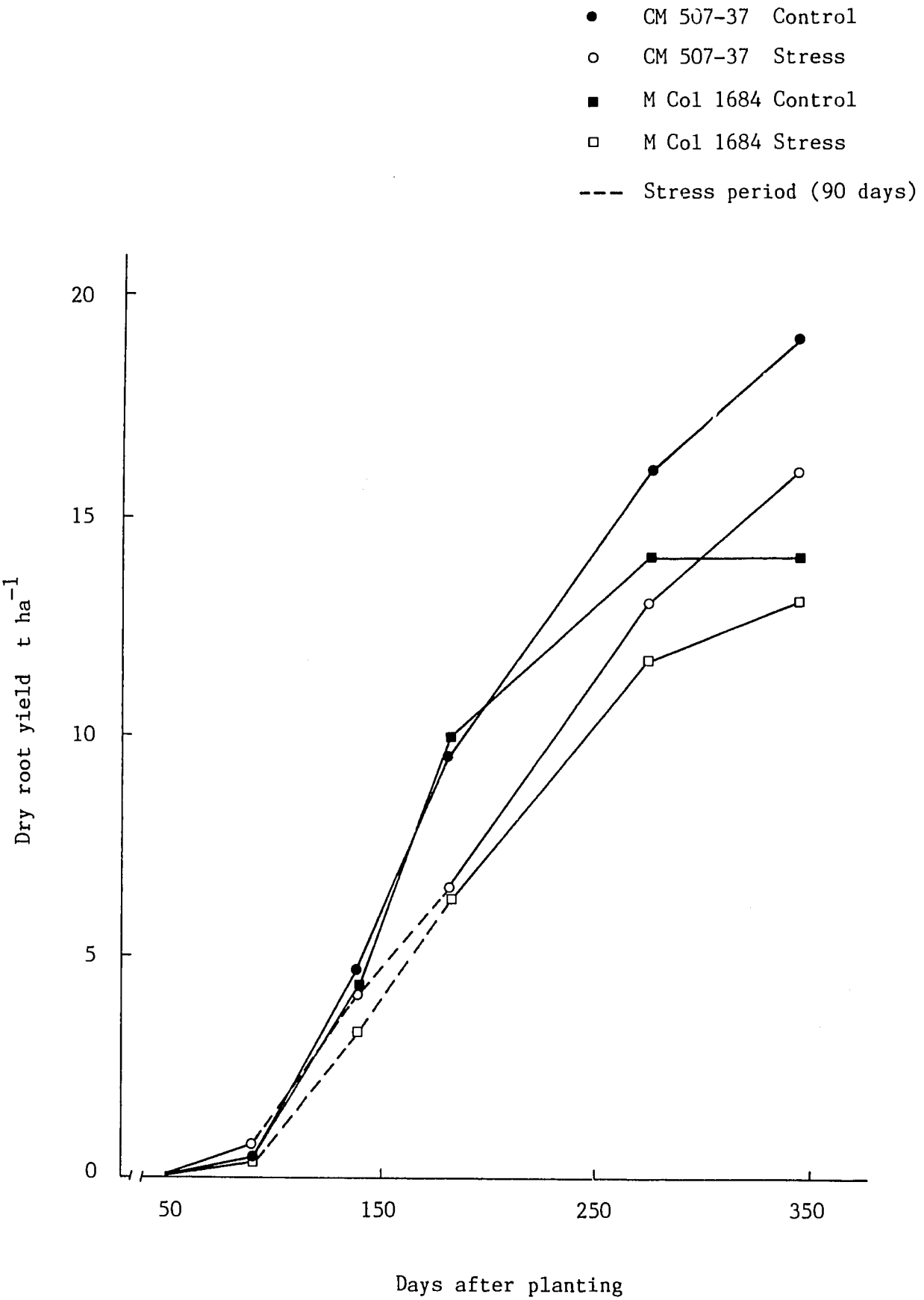


Fig. 5. Leaf Area Ratio (LAR) in the early growth stage of the hybrid CM 507-37 and the parent M Col 1684.

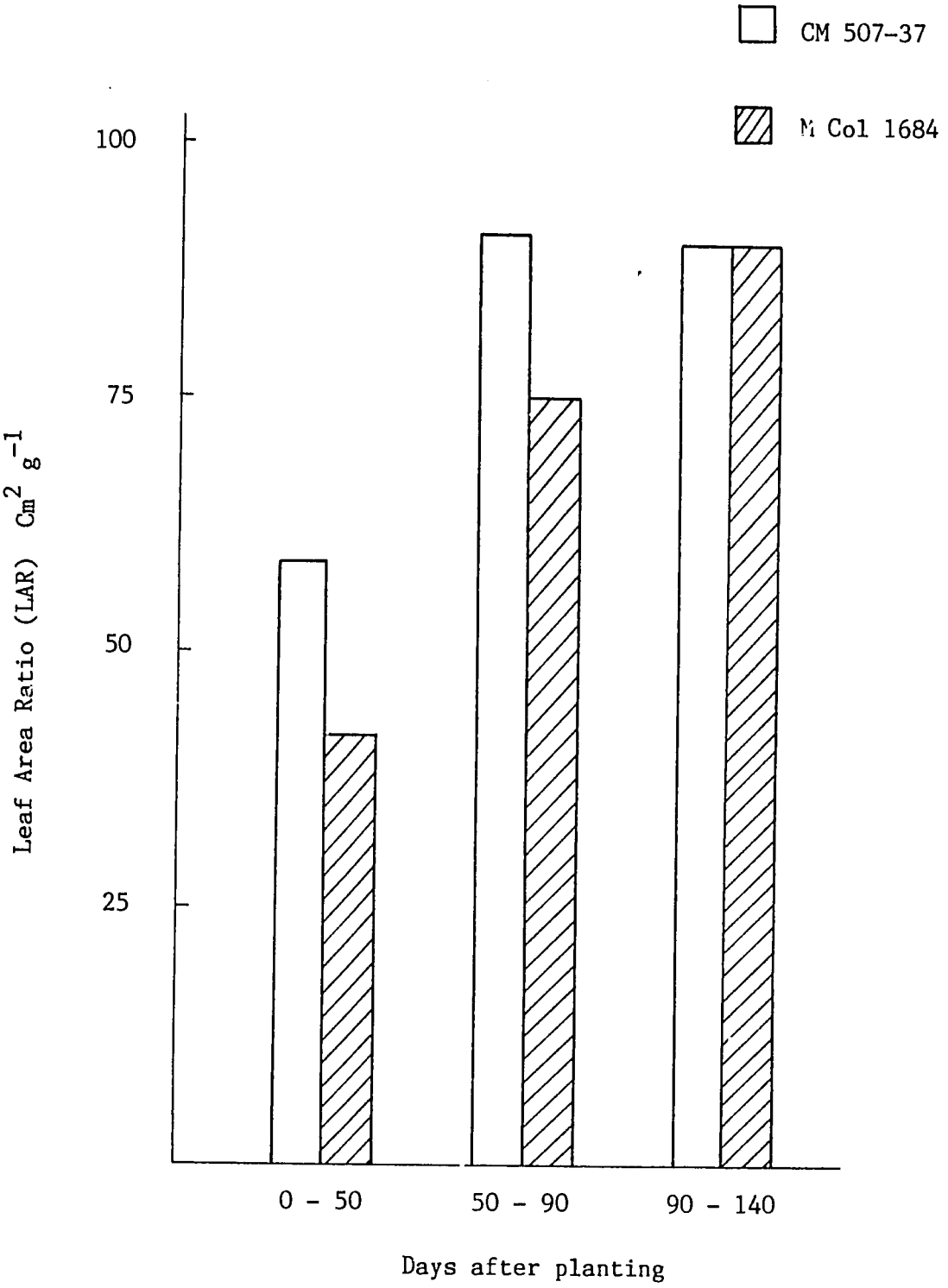
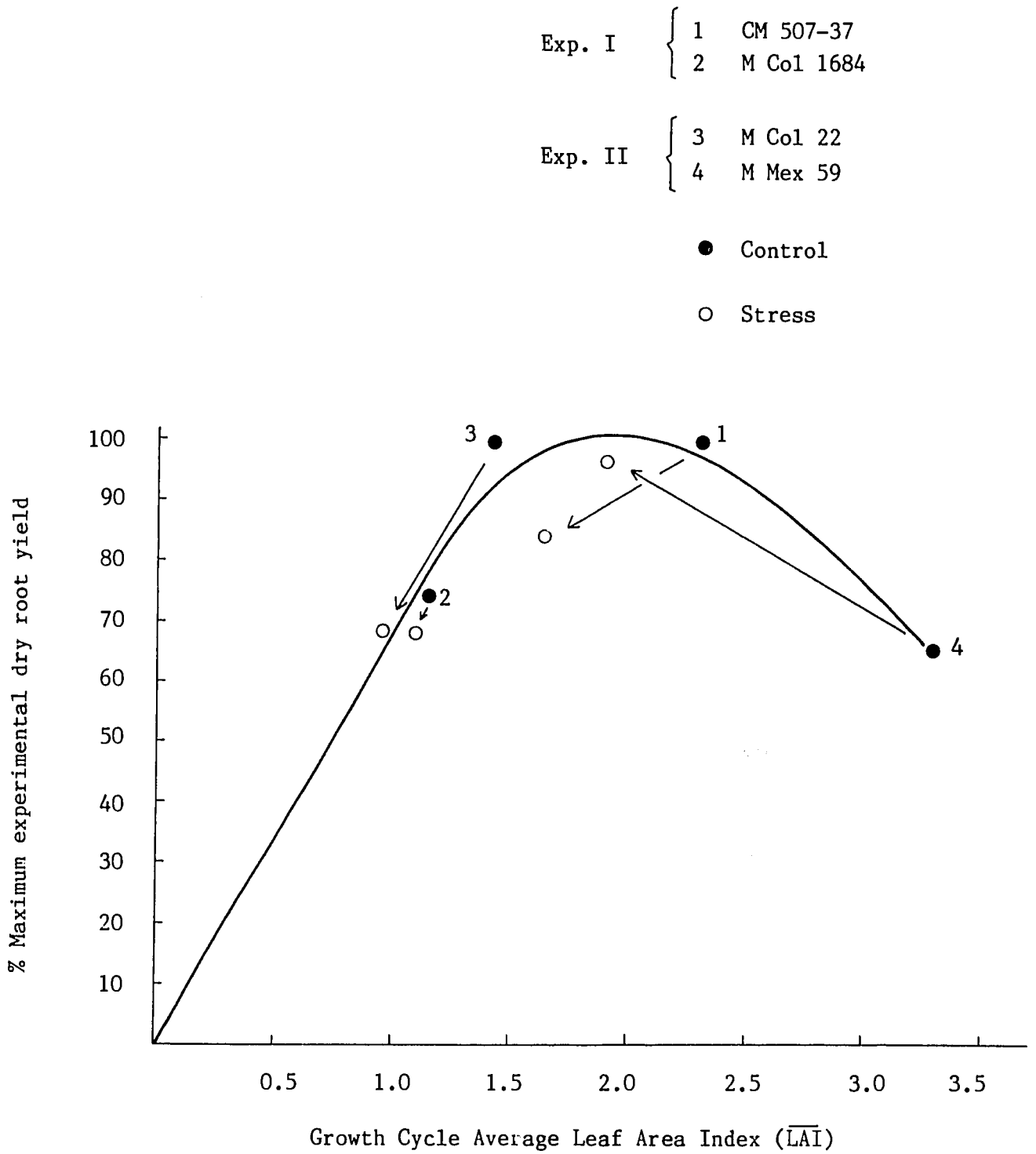


Fig. 6. Dry root yield as a function of growth cycle average leaf area index (LAI) under non-stress and mid-term water stress conditions for 4 cultivars with different vigors



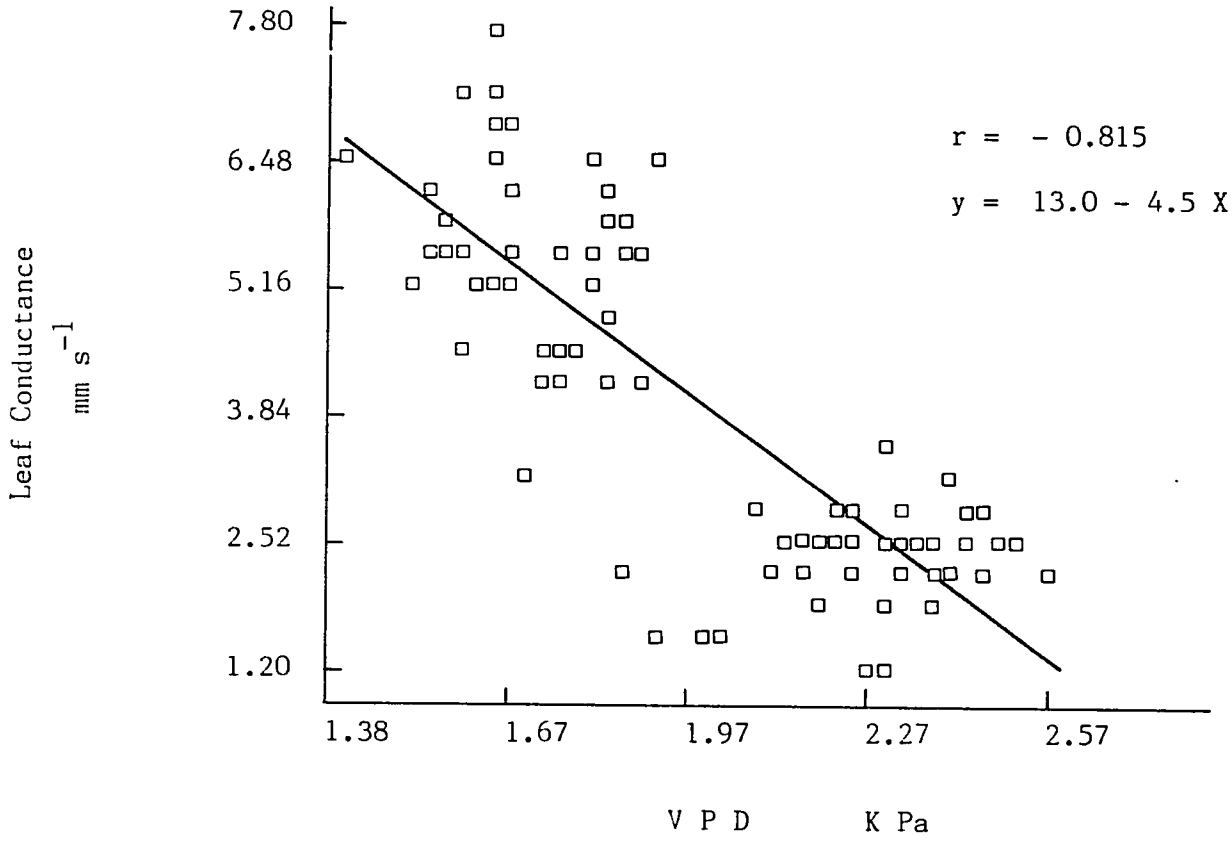


Fig. 7. Leaf conductance to water vapor as a function of leaf to air VPD for M Ven 77 grown in Carimagua Experiment Station, Colombia, S.A.

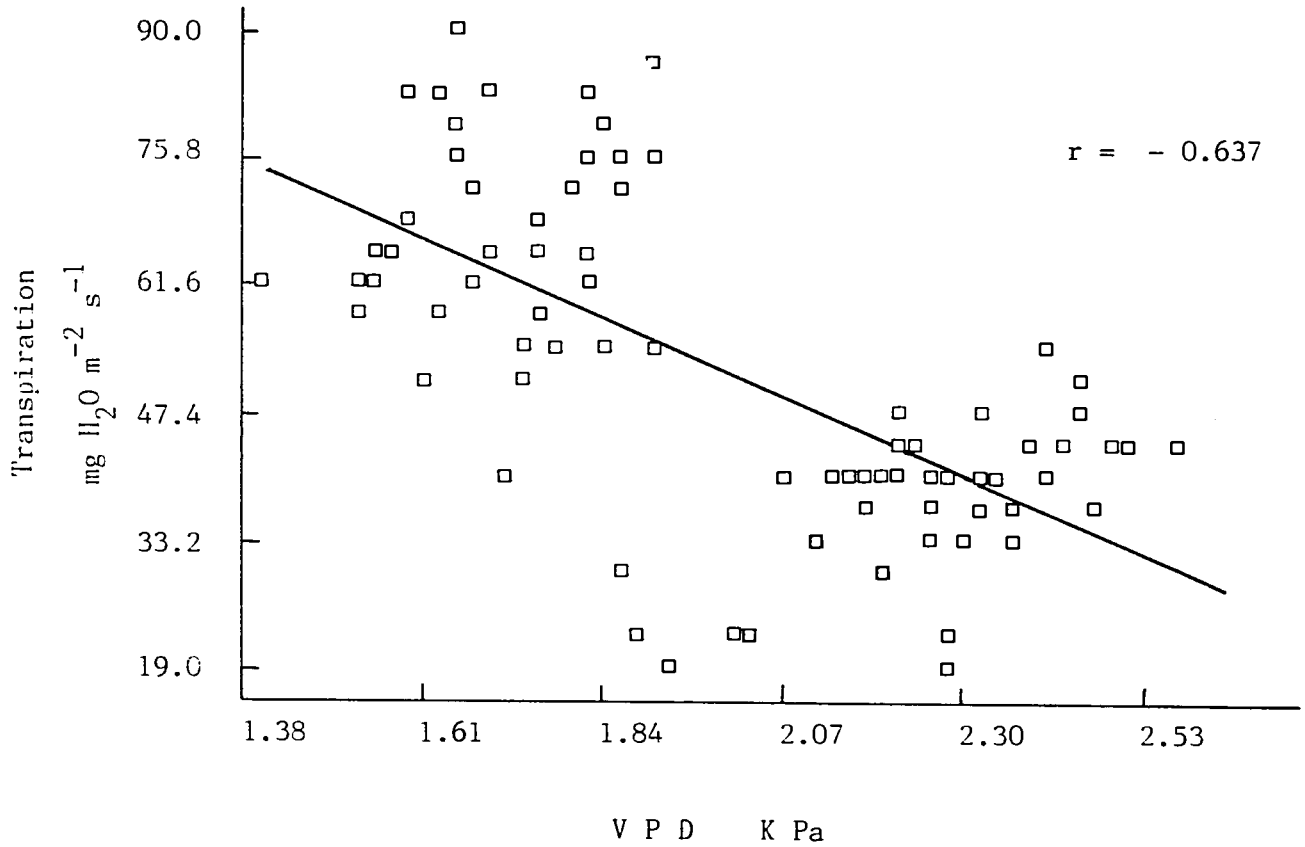
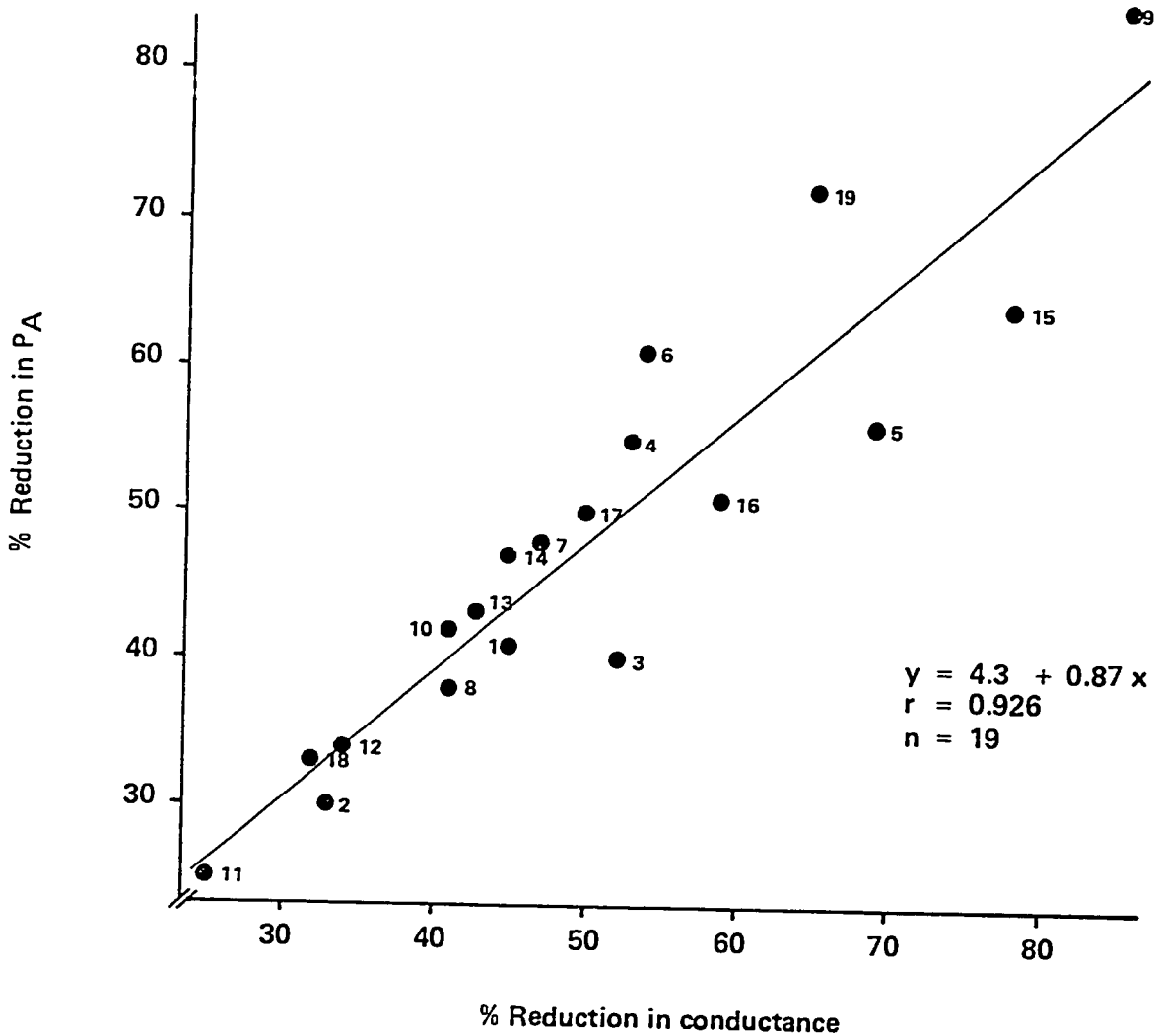


Fig. 8. Leaf transpiration rate as a function of leaf to air VPD for M Ven 77 grown in Carimagua Experiment Station, Colombia, S.A.

Fig. 9. Reduction in apparent phtosynthetic rate (P_A) as related to reduction in leaf conductance at high VPD. Numbers adjacent to data points indicate species as follow: grain sorghum (1), maize (2), andropogon (3), eucalyptus (4), mandarin (5), swinglea (6), papaya (7), cotton (8), cassava (9), cowpea (10), bean (11), mungbean (12), seed peanut (13), forage arachis (14), siratro (15), watermelon (16), squash (17), tomato (18), rice (19).



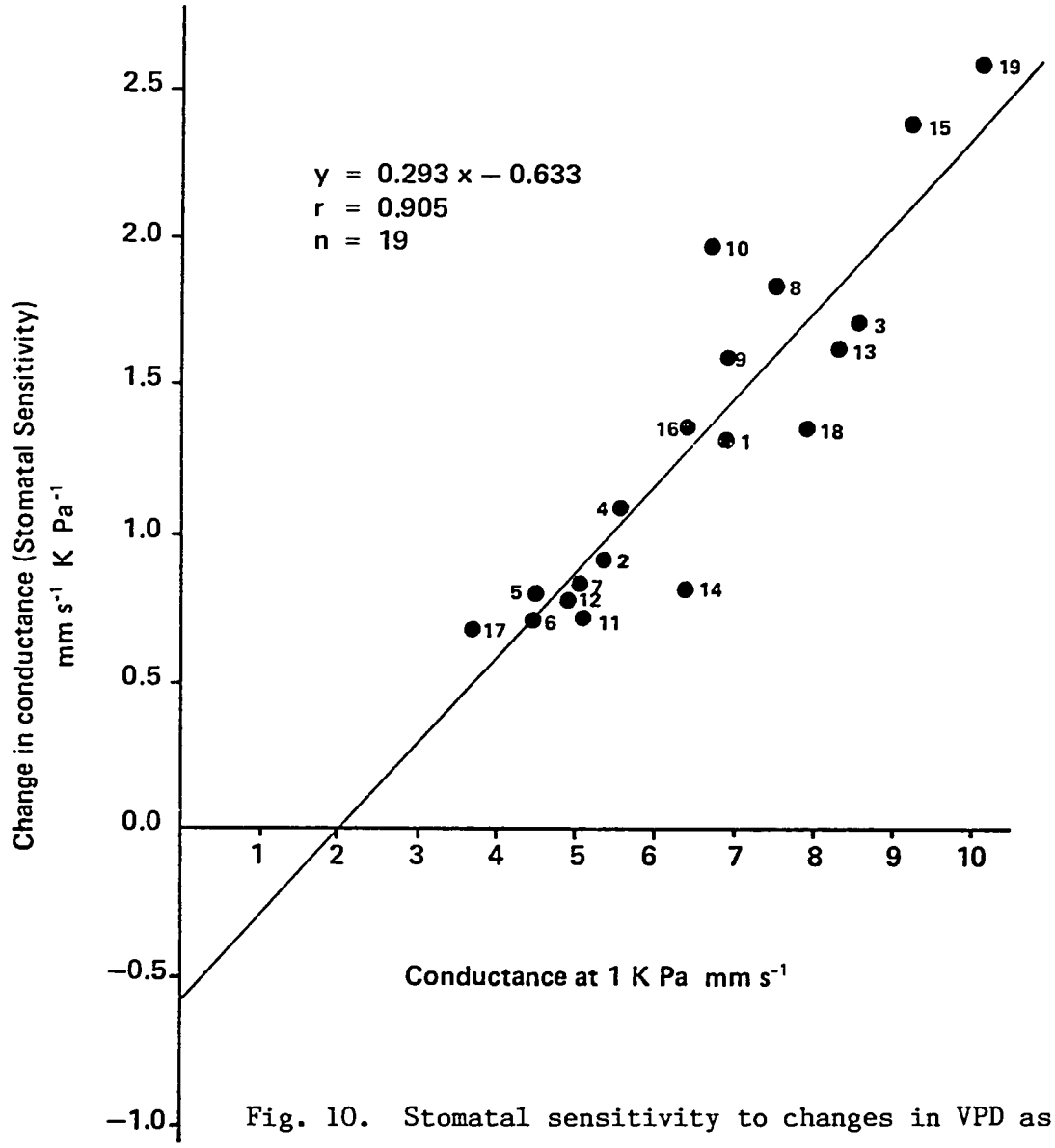


Fig. 10. Stomatal sensitivity to changes in VPD as a function of maximum conductance. Numbers adjacent to data points indicate species as in Fig. 9.

Fig. 11. Stomatal sensitivity to changes in VPD as a function of maximum conductance Numbers adjacent to data points indicate species as in fig. 9.

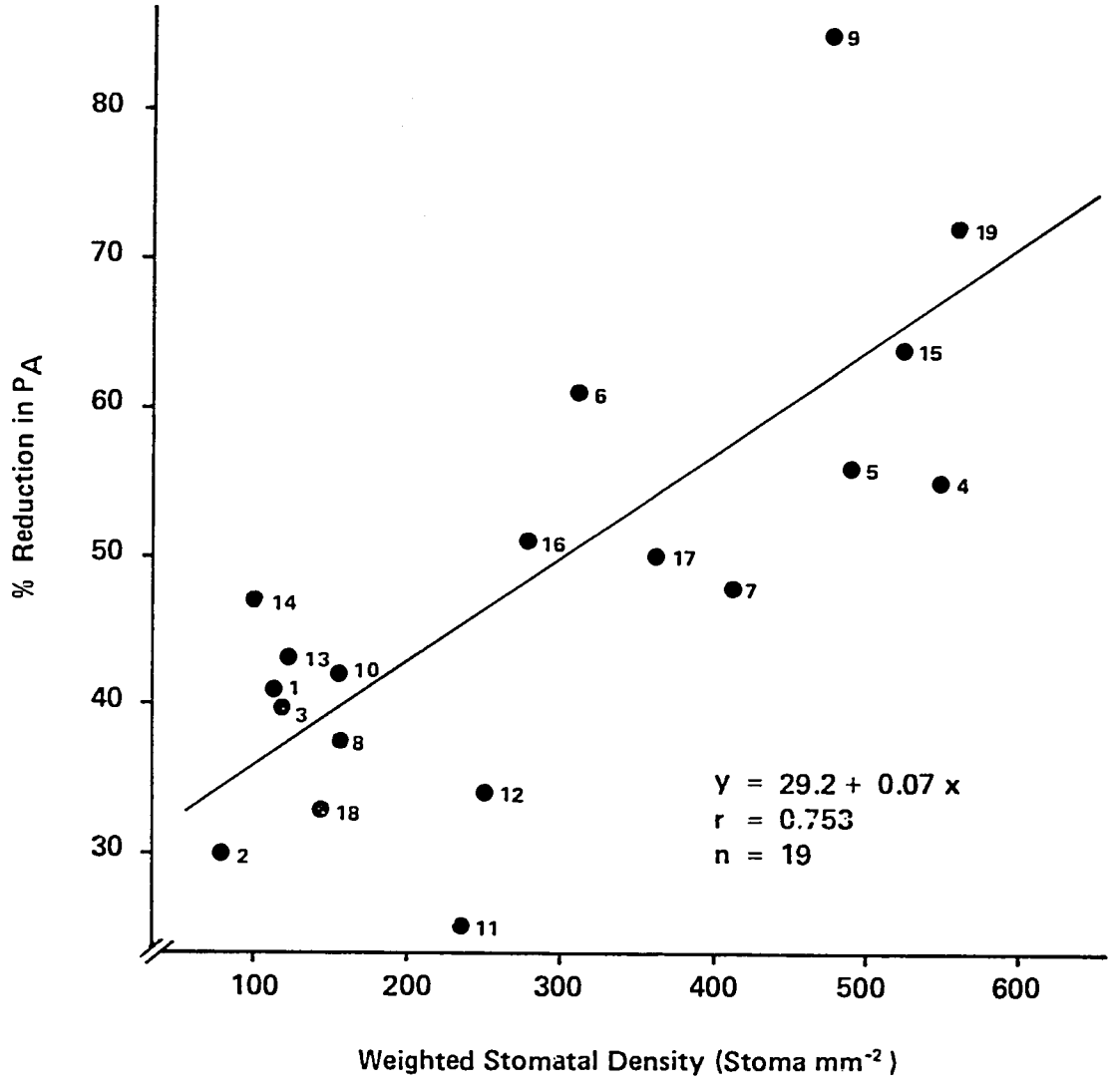
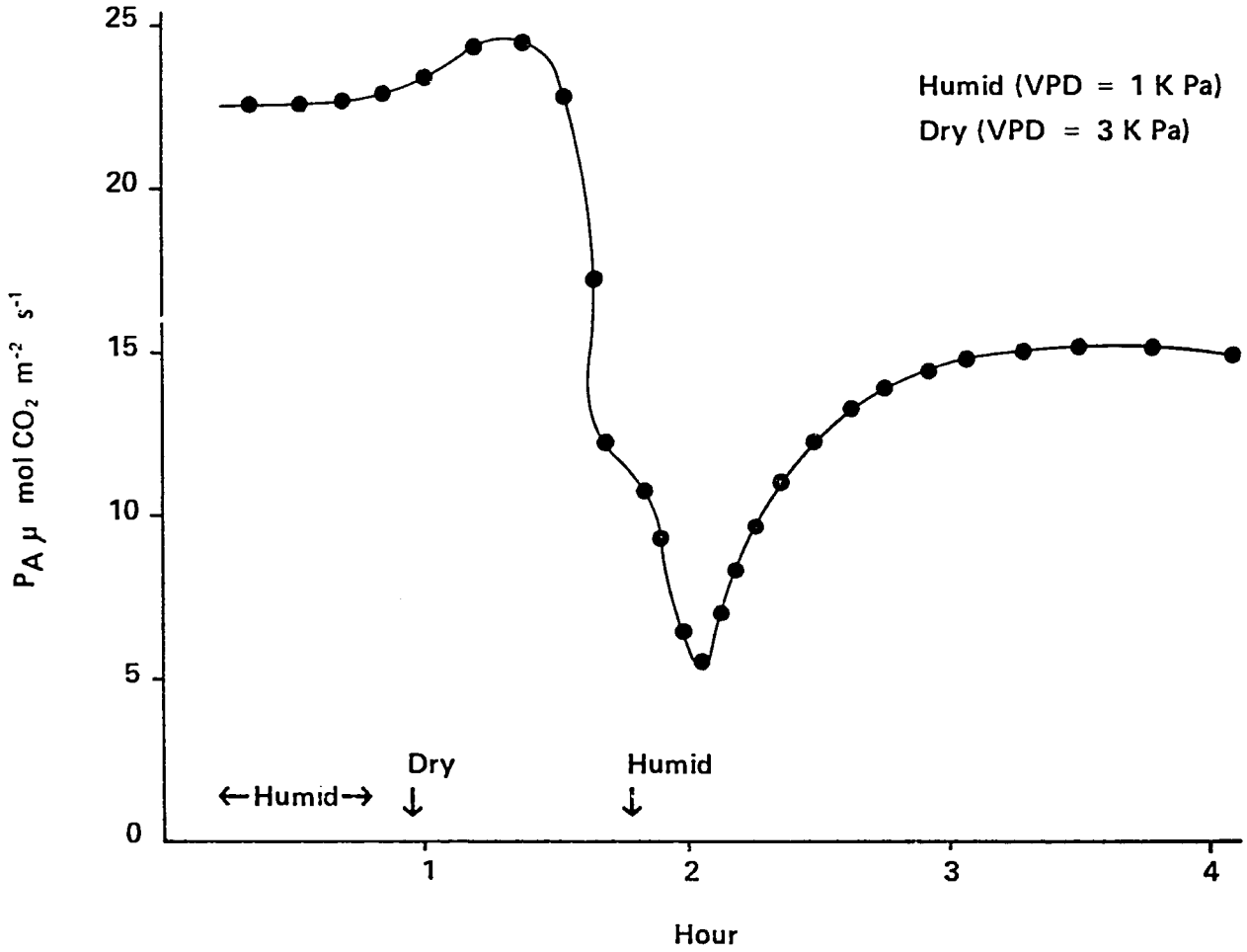


Fig. 12. Apparent photosynthetic rate (P_A) of cassava leaf as affected by cycles of humid and dry air.



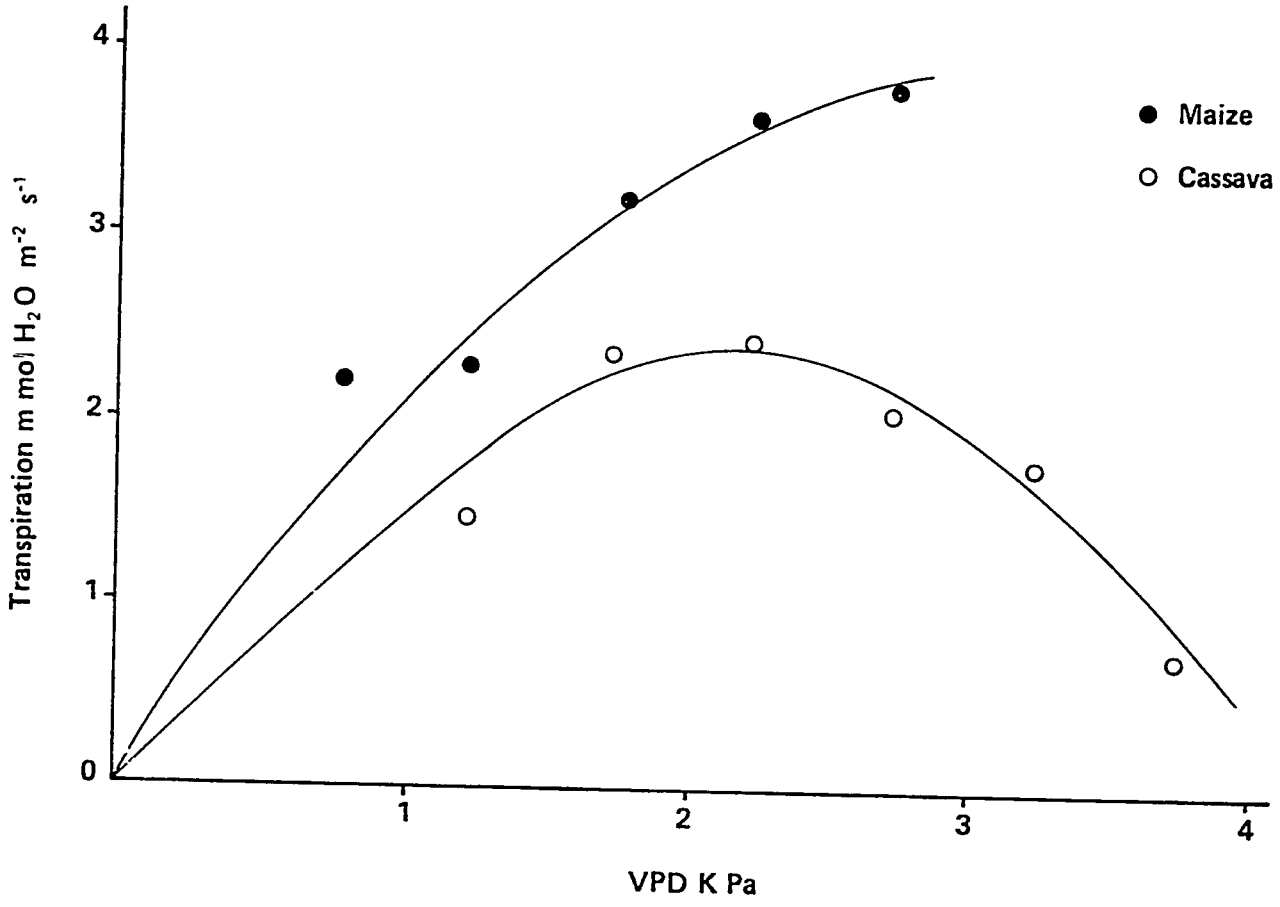
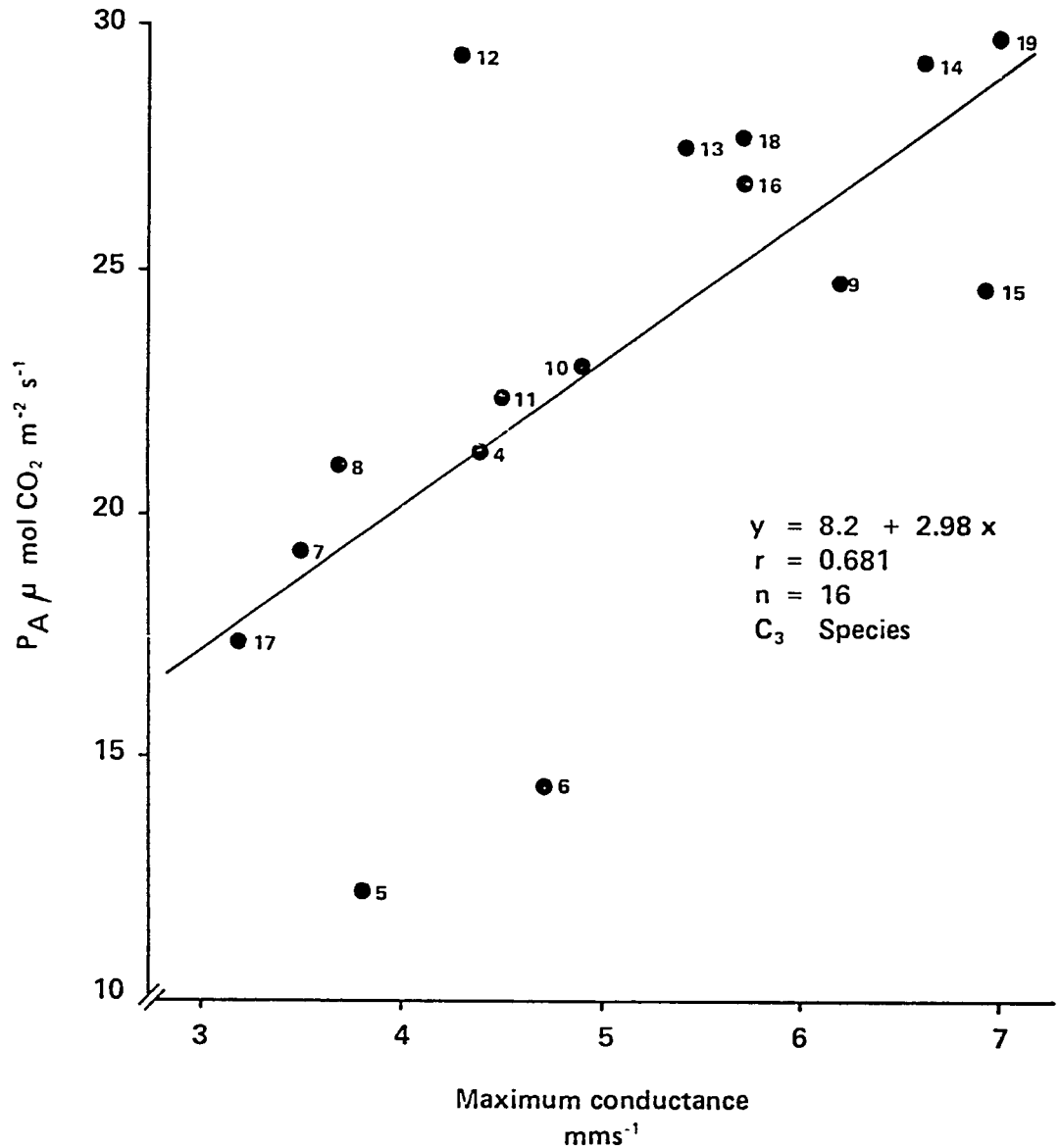


Fig. 13. Transpiration rate of cassava and maize leaves as a function of VPD.

Fig. 14. Apparent photosynthetic rate (P_A) of C3 species as a function of maximum conductance. Numbers adjacent to data points indicate species as in Fig. 9.



SOILS AND PLANT NUTRITION

Research in soils and plant nutrition during 1984 concentrated on the following aspects.

(1) Adaptation of cassava germplasm to acid low P soils.
(2) The absorption and distribution of nutrients during one growth cycle of cassava and the effect on soil fertility and mycorrhiza.
(3) The general response of cassava, rice, peanut and cowpea to NPK and lime, both in monoculture and association.
(4) The long-term effect of cassava production on soil fertility.
(5) Cassava production in exhausted soils with chemical fertilizers and/or green manures.
(6) The use of organic manures.

These aspects were studied in field trials conducted in CIAT-Quilichao, Mondomo or Carimagua, all acid, low-P soils with chemical characteristics as shown in Table 1. Except when indicated otherwise, these trials were limed with 500 kg/ha of dolomitic lime and fertilized by band application of 100 kg N, 100 kg P, 100 kg K and 10 kg Zn/ha.

Screening for Germplasm Adaptation to Low-P Soils.

While cassava as a species is highly adapted to acid infertile soils, there exist varietal differences in this adaptation.

To maximize its production potential on acid infertil soils with no or small amounts of fertilizers, the cassava germplasm collection is being screened in Quilichao for adaptation to low P, and in Carimagua to high acidity as well as to low P. In Quilichao, another 677 varieties have been screened in a single-row trial in two plots with no P and with 75 kg P/ha applied as diammonium phosphate (DAP). Both plots received 100 kg N and K/ha.

As in previous years (see Cassava Annual Reports, 1981, 82 and 83), a low P adaptation index was calculated for each variety from the product of root yields at low and high P application divided by the product of average yields for the whole trial.

Although the heavy rainfall during most of the year (2,150 mm) resulted in severe attacks of anthracnose, bacterial blight and superelongation of susceptible varieties, in general the yields were extremely high compared with previous years. The average yield without P was 20.3 t/ha while that with the application of P was 30.0 t/ha.

Some 13 varieties were selected as highly adapted to low-P soils (low P adaptation index greater than the product of average yields plus two standard deviations), and 36 varieties were considered well adapted (low P adaptation index greater than the product of average yields plus one standard deviation). These varieties will be further tested for low P adaptation in replicated yield trials.

In one of aforementioned trials, 77 varieties selected from single row trials in previous years, were grown in subplots of 30 plants with

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two replications, again in plots with no P or with 75 kg P/ha band-applied as DAP. While a few varieties were completely eliminated due to disease susceptibility, the average yield was 25 t/ha without P and 31 t/ha with applied P. Table 2 shows the root yield and low P adaptation indices of the highest yielding varieties. Several varieties were extremely well-adapted to the low P and general edaphoclimatic conditions of Quilichao, producing nearly 40-50 t/ha without any P application. These high yields in a soil with only 4-5 ppm Bray II extractable P is at least partly due to the highly efficient mycorrhizal population of the Quilichao soil.

Nutrient Absorption and Distribution as Affected by Soil Fertility and Moisture.

Nutrient absorption by cassava during its 12-month growth cycle depends on soil fertility and moisture availability. These effects were studied in Carimagua where cassava, M Ven 77, was grown in four large plots with and without applied fertilizers (1 t of 10-20-20 and 5 kg Zn/ha) and with and without gravity irrigation during the four month dry season. In four replicates of each treatment subplots of six plants were harvested each month in such a way that the remaining subplots were always surrounded by border plants. The harvested plants were subdivided into 13 samples, consisting of leafblades, petioles or stems of the upper, middle or lower part of the plant, as well as rootlets, swollen roots and fallen leafblades and petioles. The plant parts were weighed, dried and analyzed for major and minor elements. In the same subplots soil samples were taken to a 20cm depth and analyzed for available nutrients. Soil cores were also taken to a one meter depth, and divided into 20cm segments. Cassava roots in each segment were weighed and their mycorrhizal infection determined, while mycorrhizal spores were counted in the soil cores.

Figure 1 shows the dry matter accumulation during the 12 month growth cycle as affected by fertilization and irrigation. Cassava was planted in early November, about a month before the onset of the dry season. While rainfall was low from December to April, it never ceased to rain completely as normally occurs in Carimagua. Thus plant growth was not markedly affected by lack of soil moisture, and supplemental irrigation had only a minor effect. Application of fertilizer increased plant growth more markedly, and at time of harvest increased total dry matter (DM) 64% and root yield 44%. However, since the trial was located on a plot fertilized in previous years, the effect of fertilization was not as marked as would be expected in a virgin soil. DM accumulation was slow initially, but after the second month proceeded at a nearly constant rate until harvest. Figure 2 shows that initially DM accumulated mainly in leaves and stems, but already after the third month the swollen roots became the major sink, increasing steadily in weight until harvest. Due to excellent climatic conditions and good management fresh root yields were as high as 43 t/ha with irrigation and fertilization, and 28 t/ha without fertilization. Without irrigation, yields were 32 and 24 t/ha with and without fertilization, respectively. The effect of fertilization was significant, that of irrigation was not, partially due to the unusually wet dry season.

Figure 3 shows that irrigation had also little effect on the concentration of N, P and K in the upper leaf-blades. This suggests that nutrient uptake was little affected by soil moisture status. However, in both irrigated and non-irrigated plots, the concentration of all three major elements decreased markedly during the dry months from February to March and increased markedly at the onset of regular rains in April. After the new growth flush in May nutrient concentrations remained fairly constant during the rest of the growth cycle. The marked decrease in nutrient absorption during the dry season, with or without irrigation, is probably due to stomatal closing and decreased transpiration as a result of low relative humidity. In fact, measurements of leaf water potential during the dry season showed little change between 10 AM (-13.4 $\pm$ 1.7 bar) and 1 PM (-13.5 $\pm$ 2.3 bar); however stomatal conductance decreased markedly. This suggests that stomata closed due to changes in air humidity and not as a result of soil moisture deficit. Thus, transpiration and water consumption must have been reduced. At the end of the growth cycle lack of irrigation had decreased both top and root growth about equally to 86% in unfertilized and to 72% in fertilized plants, compared to those in irrigated plots.

Figure 4 shows that the inorganic N, available P and exchangeable K contents of the soil decreased during the growth cycle. Fertilized plots had initially higher levels of soil nutrients than unfertilized plots, but these differences diminished with time, due to increased nutrient absorption by fertilized plants, increased fixation of P and leaching of N and K. Fertilized plants accumulated 222 kg of N, 35 kg of P and 220 kg of K, compared with 135, 18, and 101 kg/ha, respectively, in unfertilized plants. Of the total amount of nutrients absorbed, about 25% of N, 47% of P and 56% of K was removed in the root harvest, indicating again the large removal of K in cassava roots.

In the monthly sampling of soil with a 7 cm diameter drill up to one meter depth, very few fibrous roots of cassava were encountered beyond the top 20 cm depth, indicating the sparcity of the cassava root system and its presence principally in the fertilized topsoil. Apparently, only a few roots penetrated to deeper layers for water uptake during the dry season. The few roots recovered by this sampling technique showed a low level of mycorrhizal infection from 0 to 60%. Table 3 indicates that mycorrhizal spores were mainly present in the topsoil at the early stages of growth, but increased with soil depth during the dry season due to lack of soil moisture and/or cassava roots in the topsoil. After the onset of the rainy season in May spore numbers increased again in the top layers of soil. Toward the end of the growth cycle maximum numbers of spores were found at the 60-80 cm depth. Since mycorrhizal spores only multiply rapidly in the vecinity of living roots, their presence indicates some root activity at a deeper depth, although the sampling technique did not actually encounter roots in any of the 16 cores taken monthly during the last half of the growth cycle.

Fertilizer and Lime Response of Cassava in Monoculture and Association.

The response of cassava and various other crops to the application of fertilizers and lime, both in monoculture and in association was studied in Carimagua in various systematic design trials. The application of NPK fertilizers as 10-20-20 increased systematically from

0-2 t/ha, while that of lime increased in perpendicular direction also from 0-2 t/ha (see Cassava Annual Report, 1983).

The responses of monoculture cassava, peanut, cowpea and rice to the application of NPK and to lime were similar to those reported in 1983. While peanut and cowpea reached near maximum yield with only 0.5 - 1.0 t/ha of 10-20-20 and similar amounts of lime, rice and cassava reached their highest yields only at the highest rate of application of 2 t/ha. Peanuts were most tolerant of low soil fertility while cowpea was most tolerant of high soil acidity. Cassava was relatively tolerant of both soil infertility and acidity, but required high levels of lime and fertilizers to reach maximum yields.

When grown in association, each crop at the same population as in monoculture, cassava yields were little affected by the presence of rice and peanuts, but greatly affected by the severe competition from cowpea (Figure 5). On the other hand, cowpea yields were only depressed about 25% by competition from the cassava, while peanut yields were reduced to about half and rice yields to 10% by intercropping with cassava.

All crops showed a similar response to NPK when grown in association compared with their monoculture response, but the response to lime tended to be reduced when grown in association, due to the lower yield levels obtained in each crop. Since cassava required much higher levels of NPK and lime than cowpea or peanut to reach maximum yield, the yields of the latter two crops were relatively more depressed at high levels of lime and fertilizers when grown in association with cassava.

Land equivalent ratios (LER) varied from 0.92 to 1.87 in the cassava-cowpea and from 1.10 to 2.02 in cassava-peanut association. Maximum ratios were obtained at low levels of applied lime and high levels of fertilizers in both associations.

Long-Term Fertility Trial

In 1977, a long-term fertility trial was initiated in CIAT-Quilichao to study the effect of continuous cassava on soil fertility. Three levels of N, P and K were applied in 1977 in all possible combinations and five consecutive cassava crops were grown without further fertilization (see Cassava Annual Reports, 1978 to 1983). Only in eight additional treatments were fertilizers applied annually.

The residual effect of the initial fertilizer application slowly disappeared over time and yields declined due to soil exhaustion, especially in those treatments with high P and no K applications. Thus, with the sixth crop it was decided to study the recuperation of these exhausted plots by annually applying fertilizers to only half of each plot, in amounts equivalent to each initial treatment. Figure 6 shows the average response to N, P and K in subplots having received fertilizers only in 1977 (residual effect), and those having received fertilizers in 1977 and in 1983 at planting of the sixth crop. There was a slight response only to the residual effect of K application. However, there was a highly significant response to re-application of N, P and especially K. Five consecutive cassava crops had exhausted the K levels of the soil so severely that one application of 250 kg K/ha increased

average root yields from 18 to 37 t/ha and increased soil K from 0.08 to 0.23 me/100 gm.

Figure 7 shows the relationship between cassava root yield and the K-level in youngest fully expanded leaf blades (YFEL) of four month-old plants. Maximum yields were obtained with K concentrations above the critical level of 1.8%. Only with annual application of high levels of K (250 kg K/ha) is it possible to maintain high levels of yield and adequate amounts of K in the plant and in the soil.

Figure 8 shows that reapplication of high levels of NPK with the sixth crop more than tripled yields from 13 to 45 t/ha, and produced yields equivalent to that obtained with the annual application from 1977 through 1983. While these annual applications had built up soil fertility considerably, the lack of fertilization with the sixth crop depressed yields about 15-17%. The additional harvest of only 2.5 and 5.0 t/ha of cassava would have paid for the cost of the medium and high levels of fertilization employed in this trial. Although most cassava farmers are either not able or not willing to apply fertilizers to their crop, from an economic standpoint they can hardly afford not to apply fertilizers in the poor soils where cassava is generally grown.

Recuperation of Exhausted Soil

Since 1977, five consecutive regional variety trials were grown in CIAT-Quilichao. Duplicate trials were grown side by side, one with annual application of moderate levels of lime and fertilizers and one without either application. In the fifth regional trial, average yields were 37 t/ha with fertilization, and only 9 t/ha in the unfertilized trial. To study the possible recuperation of the exhausted soil, two simple NPK trials were conducted side-by-side on the plots of the previously fertilized and non-fertilized regional trials. Dolomitic lime was uniformly applied to both trials.

Figure 9 shows that in the previously well-fertilized soil yields were very high and there was only a minor response to additional application of K. However, in the previously non-fertilized and exhausted soil, yields were much lower, but there was a marked response to high levels of N, medium levels of P, and especially to high levels of K. The highest but still modest application of 100 kg/ha of N, P and K increased yields from 13 to 29 t/ha, but this level of fertilization could not recuperate cassava yields to those levels obtained in the non-exhausted soil. Again K was the most limiting nutrient in the exhausted soil, but N and to a lesser extend P were also essential elements.

In the same exhausted soil a green manure trial was planted to study the potential value of green manures in the recuperation of exhausted soils. Eight legumes were planted in March 1983 after a uniform incorporation of 1 t/ha of lime and band application of 250 kg/ha of 10-30-10 fertilizers. In the case of cowpea and peanut, grain was harvested after four months. All other legumes were cut at ground-level after six months, and the top growth was chopped up and incorporated with a mini-tractor. A month later cassava was planted, either with or without an additional 500 kg/ha of band-applied 10-30-10.

Figure 10 shows the cassava response to green manure incorporation in the absence or presence of chemical fertilizers. The 10-30-10 alone increased yields from 17 to 32 t/ha, but incorporation of kudzu, zornia or peanuts increased cassava yields another 7-11 t/ha in the presence of fertilizers and 7-12 t/ha in its absence. Kudzu markedly increased both the available P and exchangeable K content of the soil at time of cassava planting, while zornia mainly increased the P, and peanuts mainly the K content. Incorporation of velvet bean or cowpea had only a minor positive effect on soil P and K levels as well as on cassava yields in the absence of fertilizers, while having a negative effect in the presence of fertilizers. Thus, incorporation of certain green manures can partially replace the use of chemical fertilizers and can greatly improve the response to fertilizers in exhausted soils.

Use of Organic Manures in Cassava

In the Mondomo region in the northern part of Cauca department, cassava is about the only crop that can be grown on the extremely acid, infertile and eroded soils. While farmers generally do not apply chemical fertilizers they will in certain cases use organic manures, principally chicken manure. To study the efficiency of these manures compared with chemical fertilizers and rock phosphates, three levels of cow manure, chicken manure, 10-30-10 chemical fertilizers and a combination of 10-30-10 and rock phosphate were applied. The manures and rock phosphate were broadcast and incorporated, while the 10-30-10 was band-applied at planting. The levels corresponded to 0, 25, 50 and 75 kg P/ha.

Figure 11 shows the response to these applications. While the average farmer's yield in the area is about 5-10 t/ha, good management, a relatively fertile soil and excellent weather conditions resulted in a high yield of 19 t/ha without any application of fertilizers. Application of rock phosphates plus 10-30-10 increased yields only slightly, while chemical fertilizers alone increased yields to 23 t/ha, but not consistently. Cow manure and especially chicken manure gave excellent yields to up to 25 and 31 t/ha, respectively. The total nutrient content of the applied chicken manure was considerably higher than that of the chemical fertilizer, but its greater beneficial effect must be also due to improved soil structure, presence of essential elements other than NPK and the stimulation of micro-organism such as mycorrhiza. This latter effect should be investigated. Although results from similar trials in previous years have generally shown that chemical fertilizers are equivalent or superior in enhancing cassava yields, the data from this trial indicate that farmers are probably correct in preferring chicken manure over chemical fertilizers. If chicken manure is locally produced and transport costs are minimal then it is also more economical than chemical fertilizers. However, high costs of transport and handling of such a bulky material in regions of few good roads, may make its use uneconomical compared with chemical fertilizers. For instance, the high level of application of 75 kg P/ha would require only 575 kg/ha of 10-30-10, 4,300 kg of dry chicken manure and 55 tons of fresh cow manure. The latter would be clearly impractical.

Table 1. Chemical characteristics of the soil in Quilichao, Mondomo and Carimagua.

Location	% O.M.	pH	ppm P	me/100 gm Al	Ca	Mg	K
Quilichao	7.5	4.5	2.2	4.3	0.87	0.22	0.15
Mondomo	6.4	4.1	2.0	3.6	0.34	0.10	0.10
Carimagua	3.8	4.4	3.2	2.7	0.43	0.13	0.08

Table 2. Root yield and low-P adaptation index of 10 varieties best adapted to the low-P soils of Quilichao.

Variety	Root yield (t/ha) oP[a]	75P[a]	low P Adaptation index[b]
M Bra 30	52.4	49.6	3.35
M Bra 33	41.3	50.8	2.70
CM 489-1	35.2	51.8	2.35
M Col 1514	37.8	48.0	2.34
CM 430-37	35.8	46.9	2.16
CM 523-7	35.2	46.9	2.13
M Ven 321	36.9	42.6	2.02
M Bra 36	35.5	42.6	1.95
M Bra 41	34.4	41.2	1.83
M Ven 310	31.6	44.1	1.80

[a] P application in kg P/ha

[b] low-P adaptation index = $\frac{\text{yield oP x yield 75 P}}{\text{x yield oP x x yield 75P}}$

Table 3. Mycorrhizal spores at different soil depths during a 12 month growth cycle of cassava in Carimagua.

Soil depth (cm)	Number of spores/100 gm dry soil											
	D	J	F	M	A	M	J	J	A	S	O	N
0 - 20	-	120	27	2	20	35	147	200	197	676	388	244
20 - 40	-	32	40	10	100	38	139	209	499	603	279	348
40 - 60	-	24	114	46	166	76	71	180	456	285	503	467
60 - 80	-	0	9	12	231	66	10	112	276	374	569	249
80 - 100	-	0	0	0	17	36	5	46	78	269	295	134

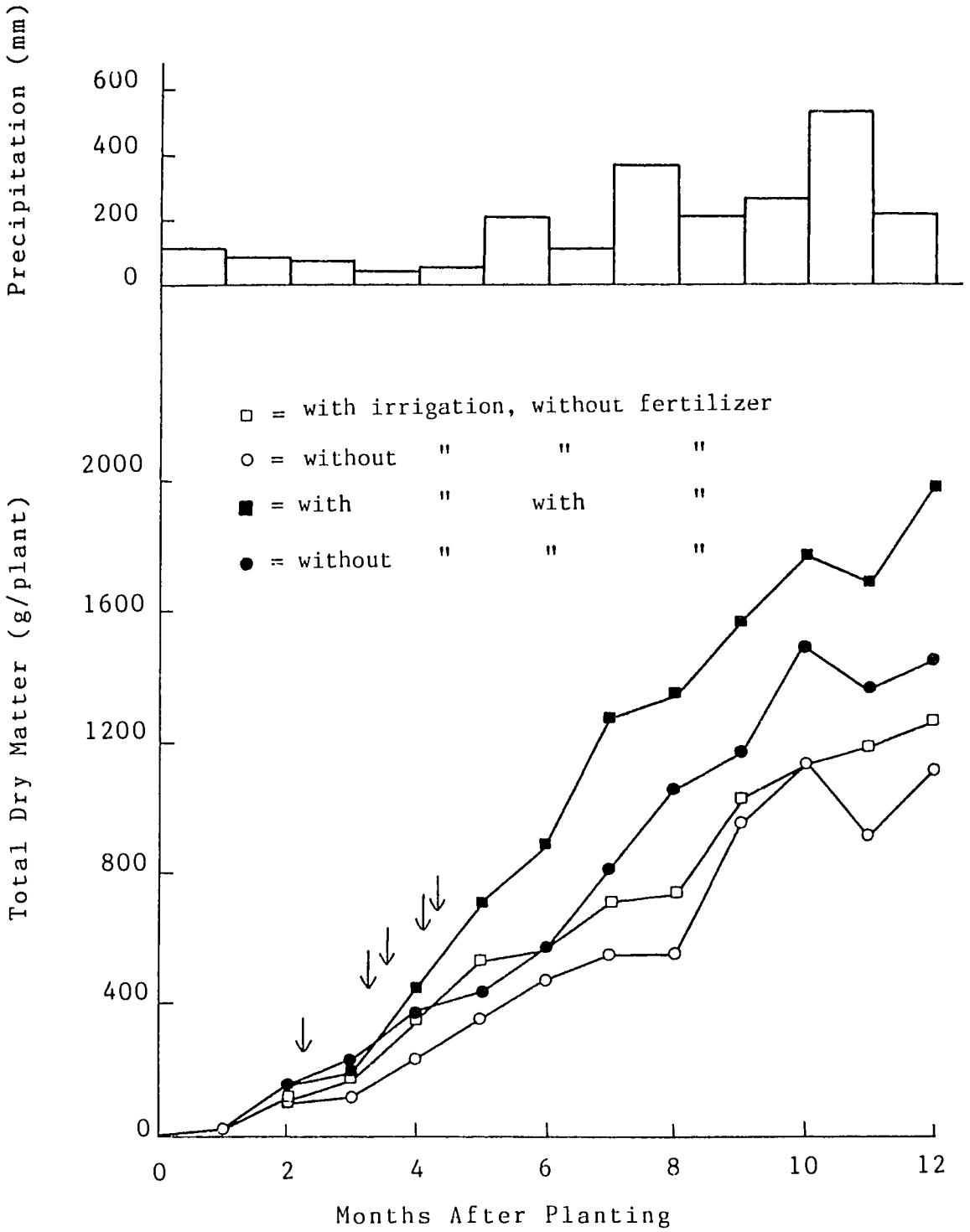

Figure 1. Total dry matter accumulation of cassava, M Ven 77, as affected by fertilization and gravity irrigation during a 12 month growth cycle in Carimagua. Arrows indicate when irrigation was applied.
Top graph indicates monthly precipitation during the growth cycle.

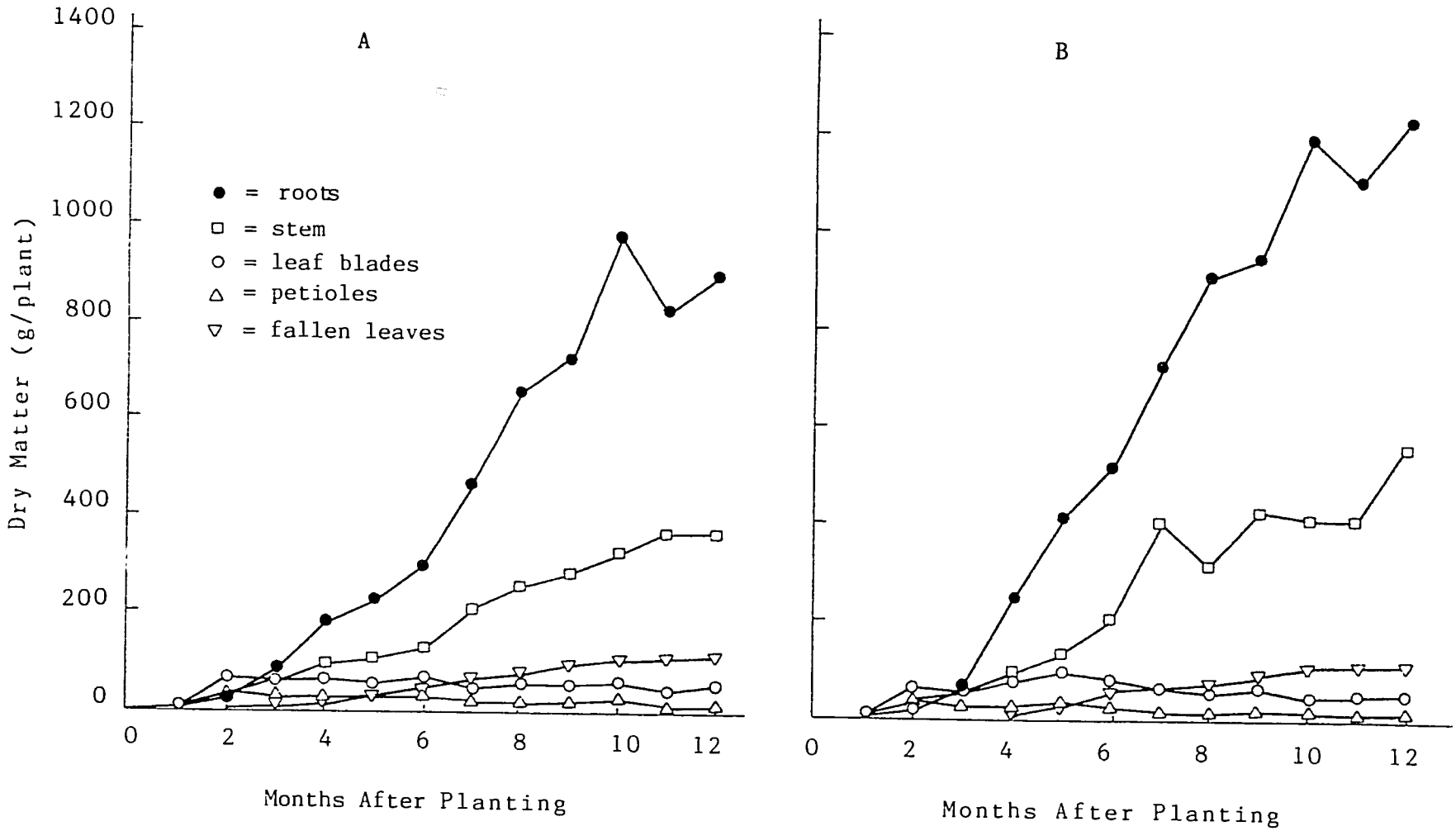

Figure 2. Dry matter distribution between roots, stems, leafblades, petioles and fallen leaves of fertilized cassava during a 12 month growth cycle in Carimagua without (A) or with (B) irrigation.

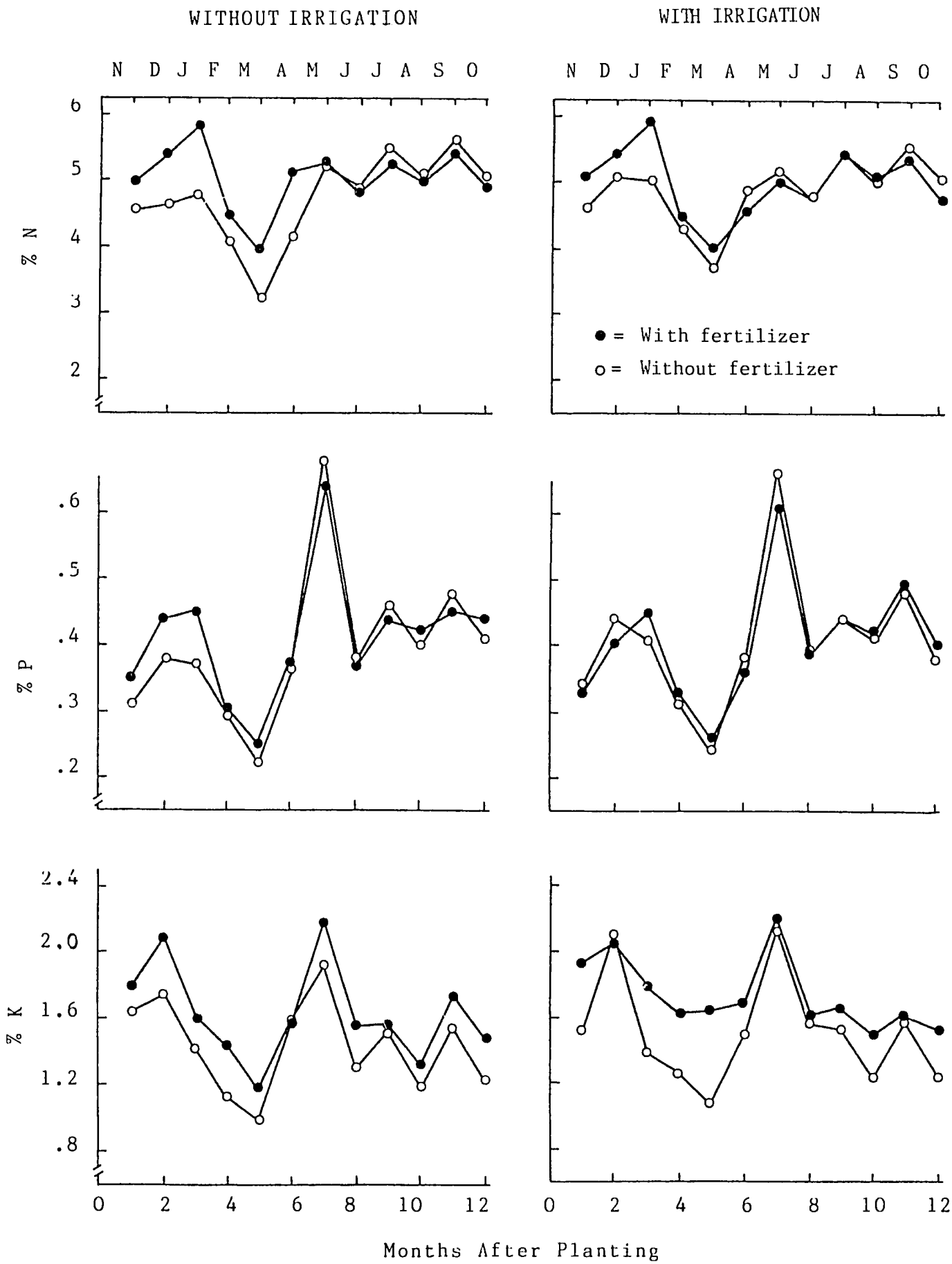

Figure 3. N, P and K concentration of upper leafblades of cassava as affected by fertilizer and gravity irrigation during a 12 month growth cycle in Carimagua.

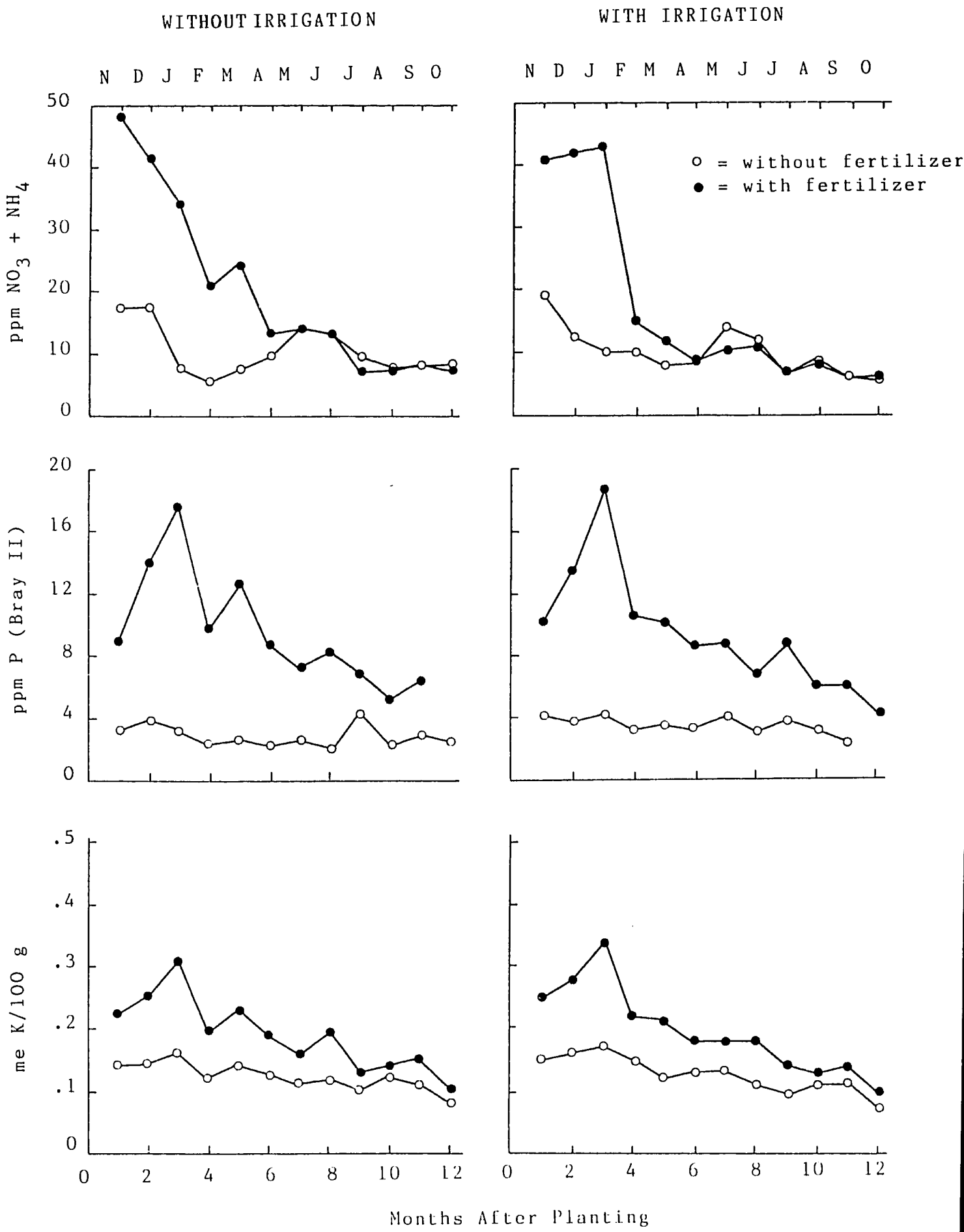

Figure 4. Change in inorganic N, available (Bray II) P and exchangeable K in Carimagua soil during a 12 month growth cycle of fertilized and unfertilized cassava.

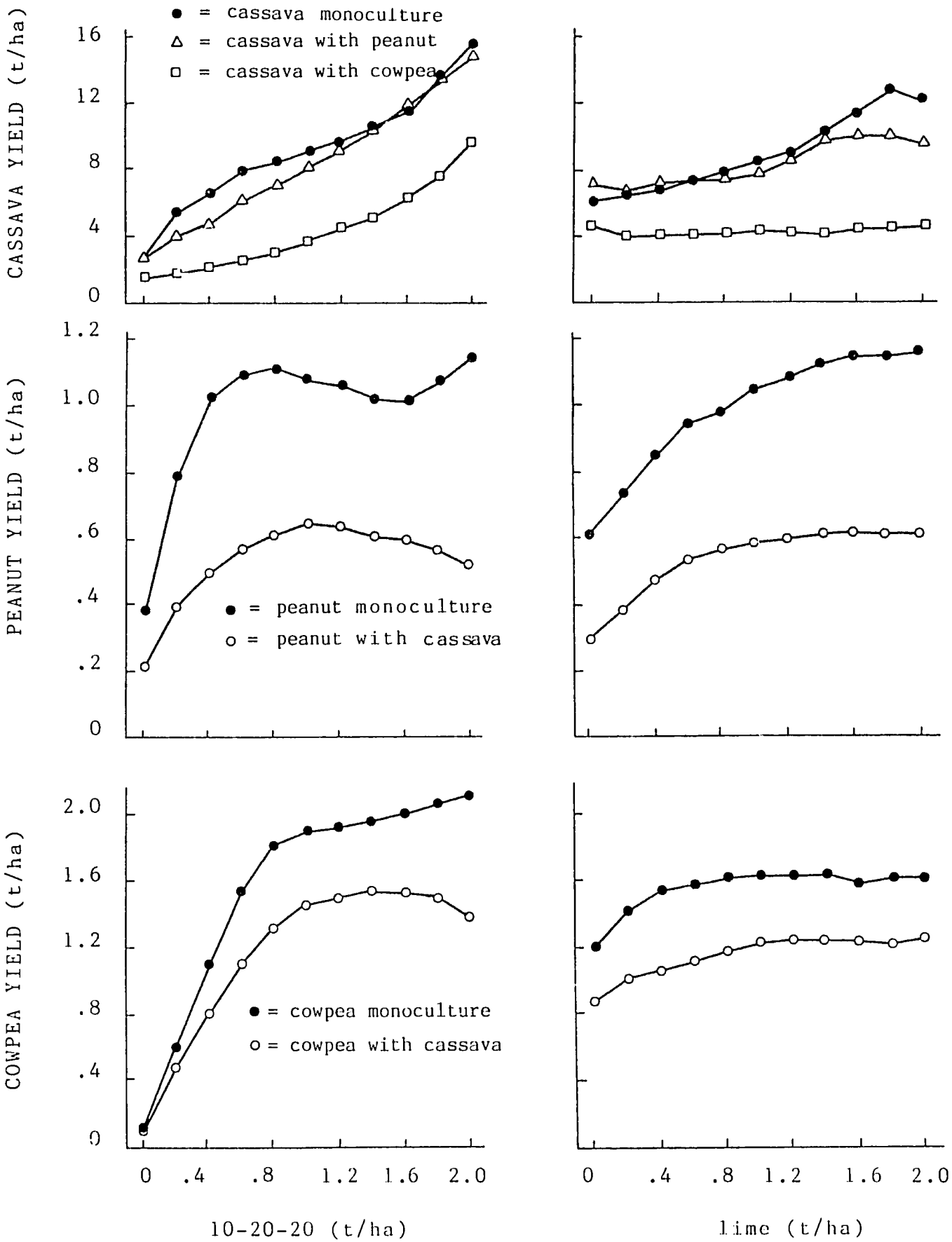

Figure 5. Response of cassava, cowpea and peanut, grown in monoculture and intercropped, to the application of 10-20-20 fertilizer and lime in Carimagua.

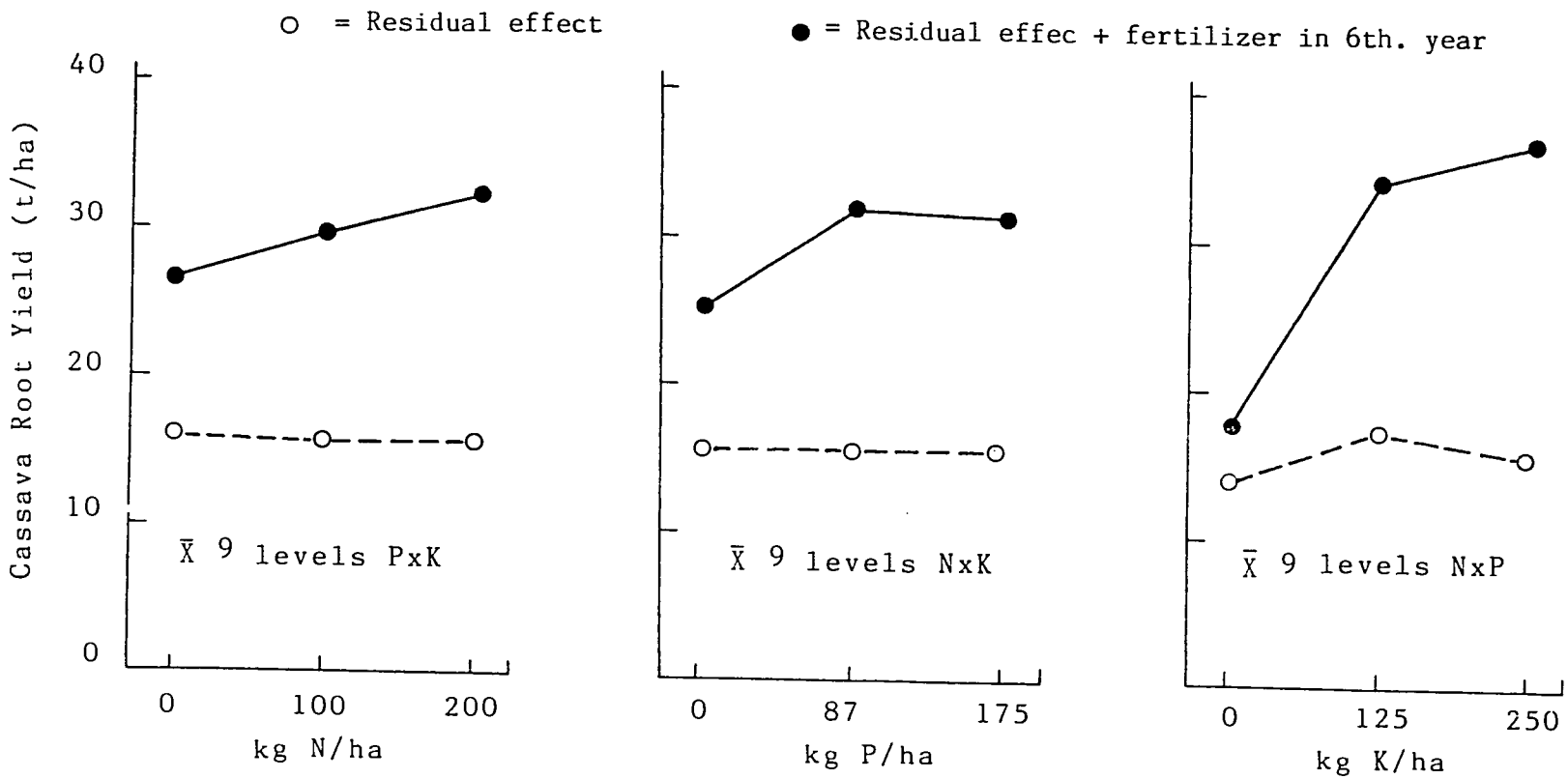

Figure 6. Average response of the sixth consecutive cassava crop to the residual effect of N, P, and K applied in 1977 and to that applied in 1977 and in 1983 before planting the last crop in Quilichao.

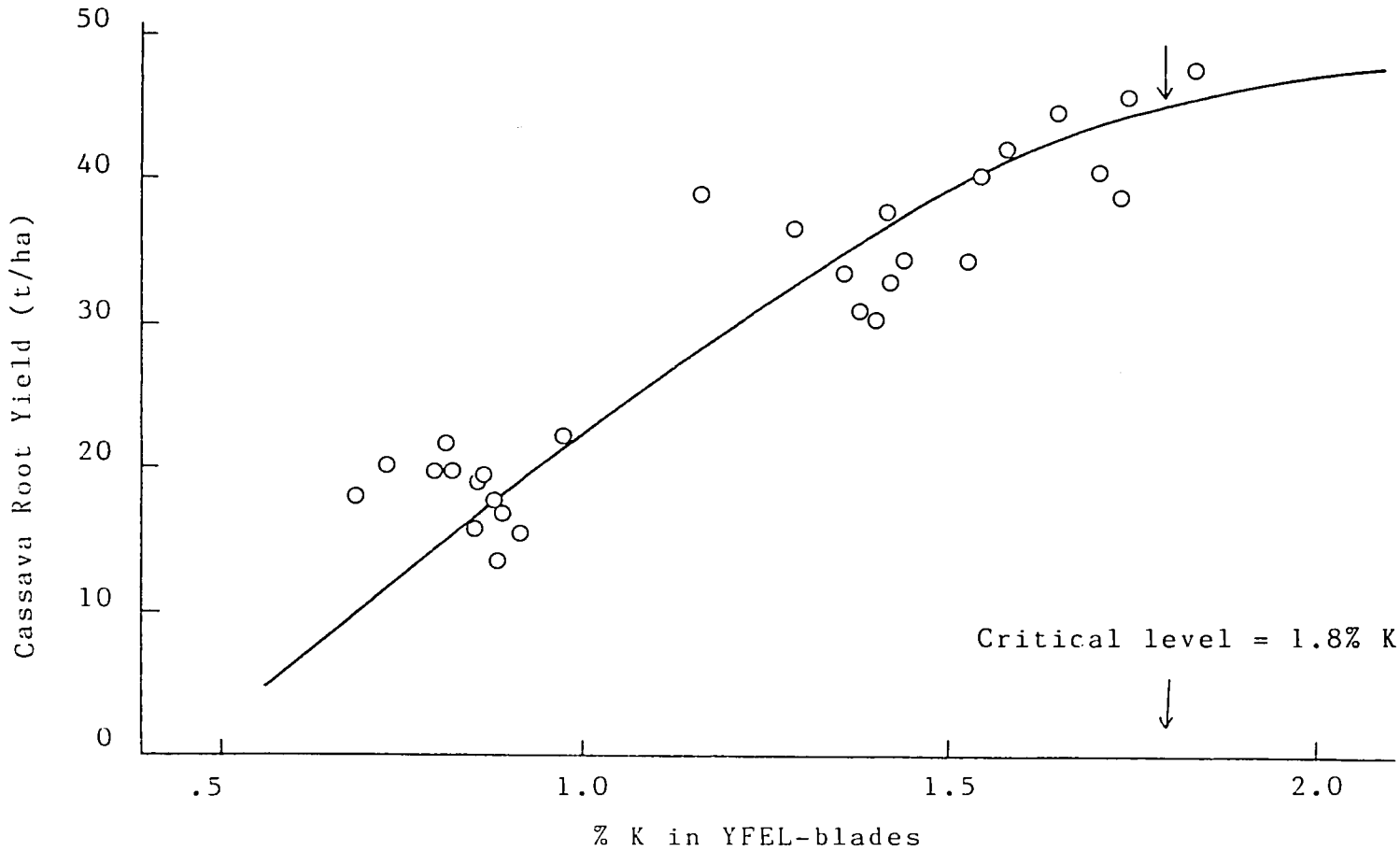

Figure 7. Relation between cassava root yield and the percentage K in youngest fully expanded leafblades of four month old cassava, CMC 40 in Quilichao.

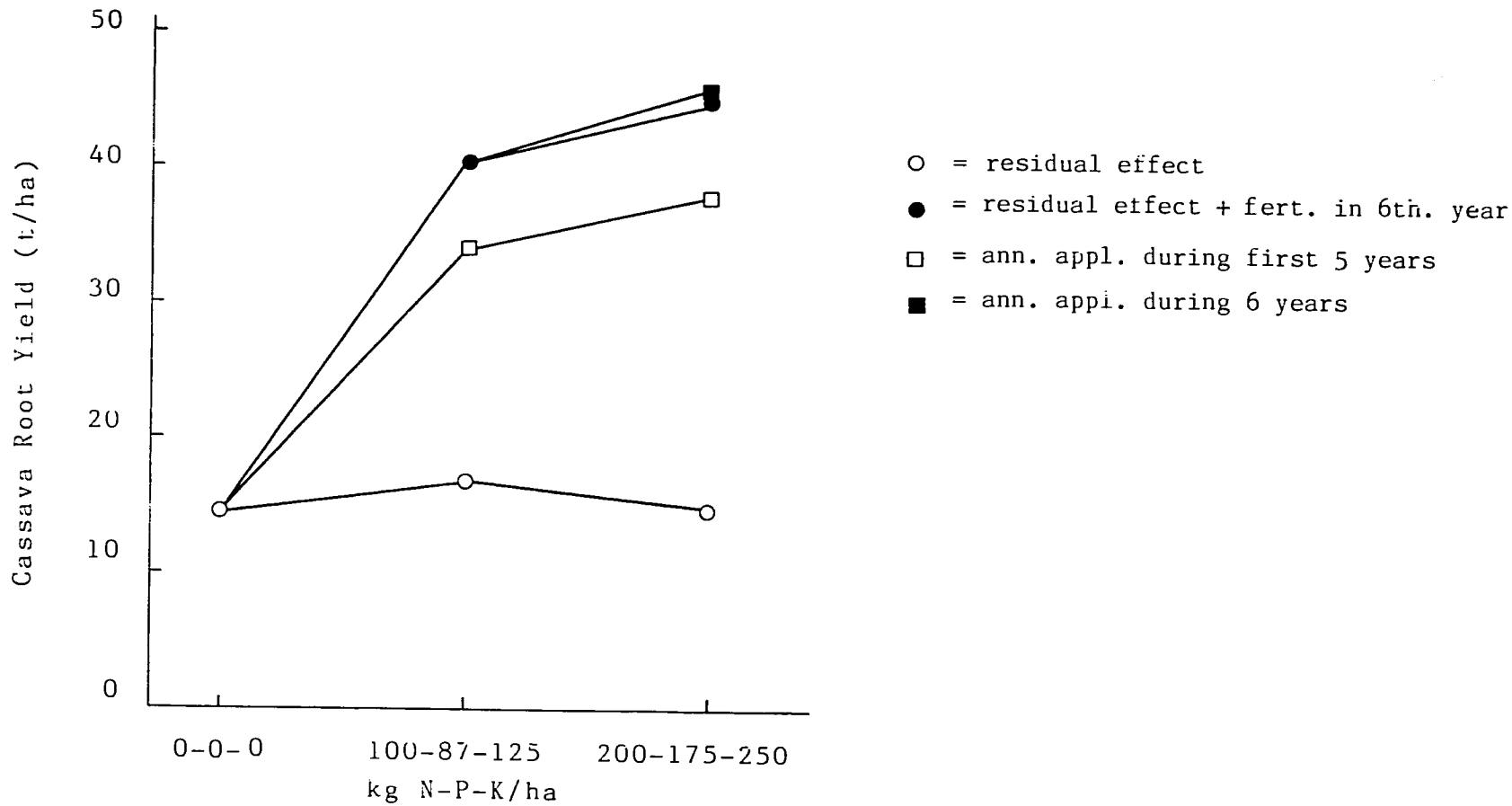

Figure 8. Response of the sixth consecutive cassava crop to three levels of N-P-K, applied either only with the first crop, with the first and sixth crop, annually with the first five crops, or annually with all six crops in Quilichao.

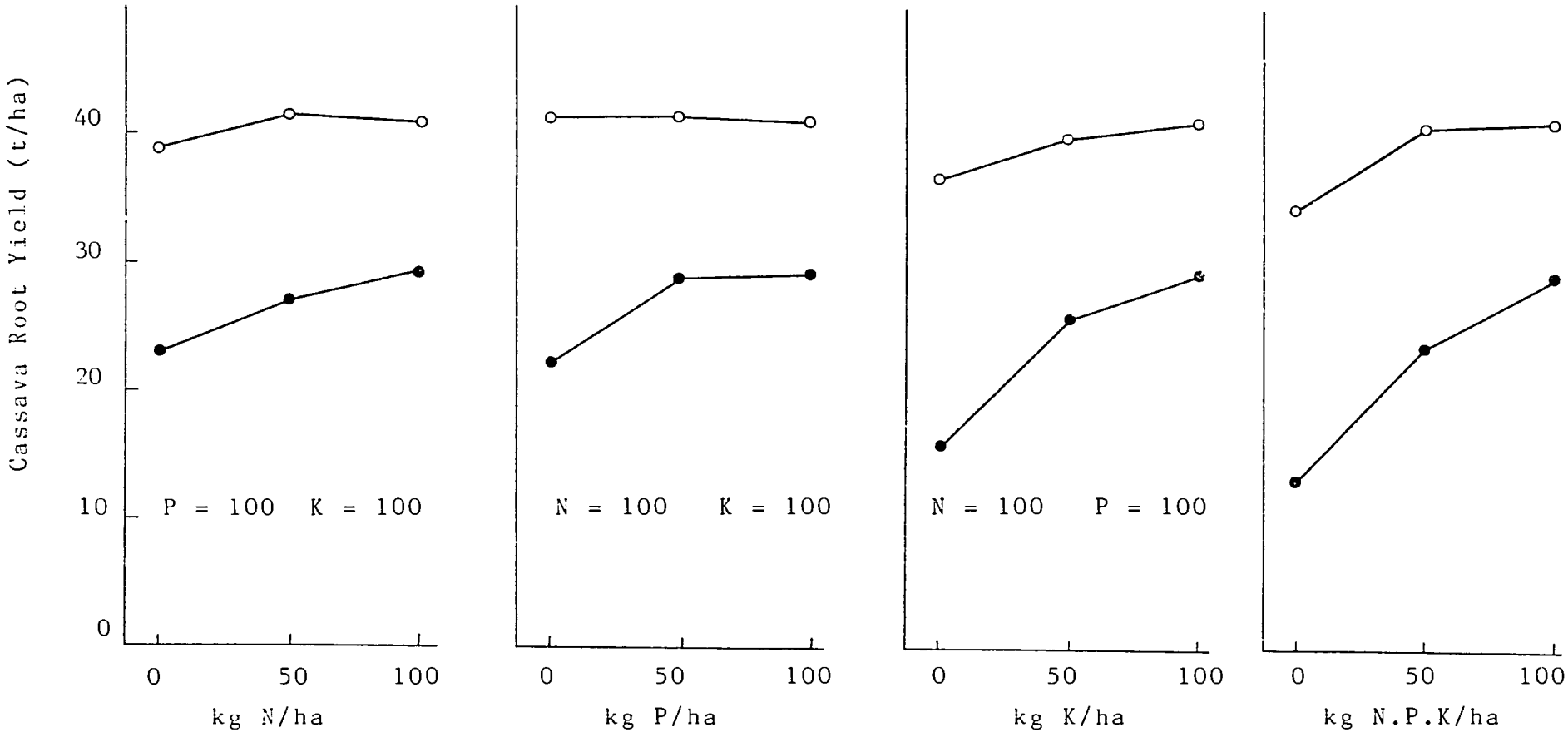

Figure 9. Cassava responses to application of N, P, and K both in a plot that had been well fertilized (open symbols) and in a plot of exhausted soil due to cropping without fertilization (closed symbols) in Quilichao. Data are average yields of M Col 1684 and CM 91-3.

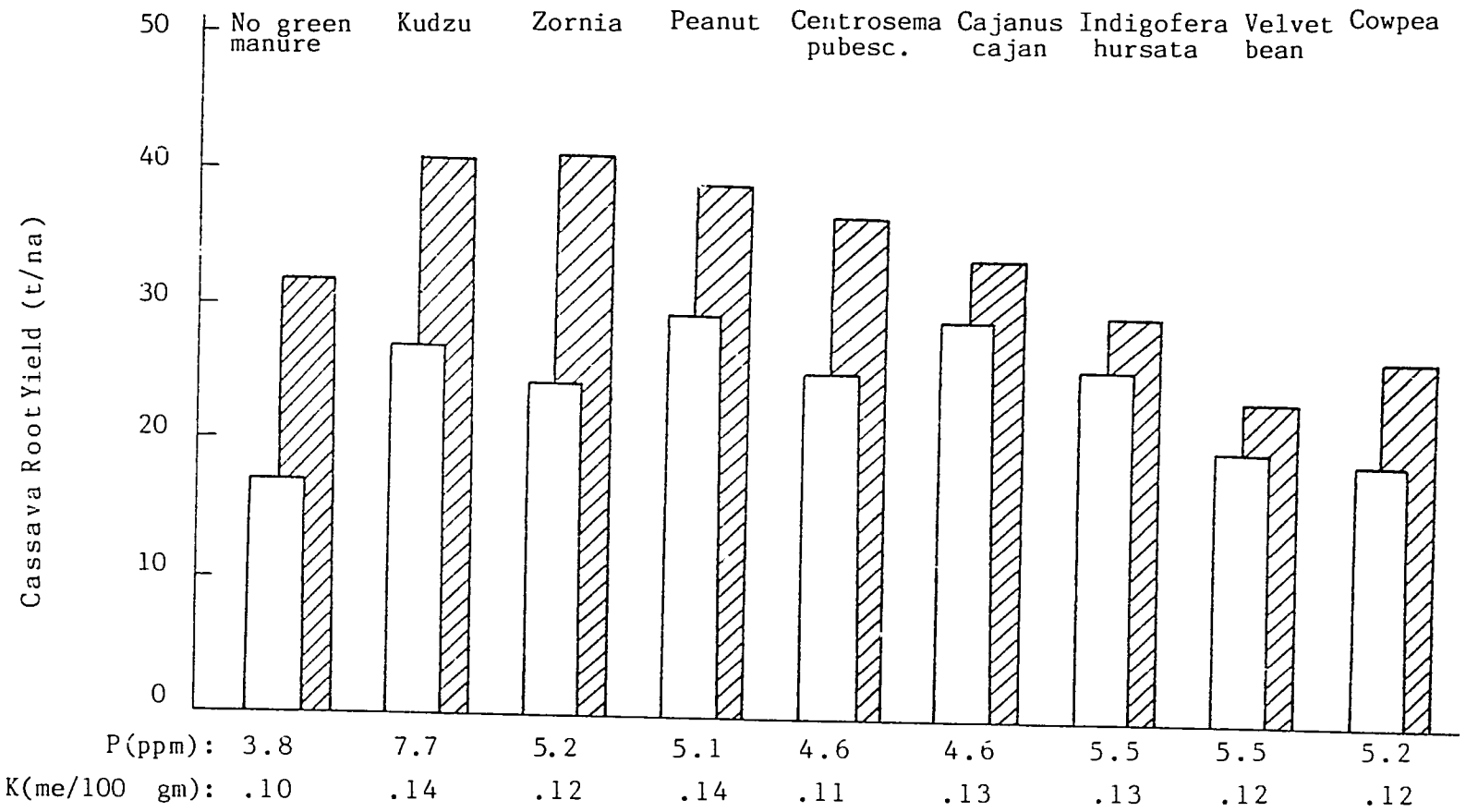

Figure 10. Response of cassava, M Col 1684, to incorporation of several green manure legumes both in the absence (open bars) and in the presence of 500 kg/ha of 10-30-10 (striped bars). Numbers below the bars indicate the available P and exchangeable K contents of the soil just before planting cassava in Quilichao.

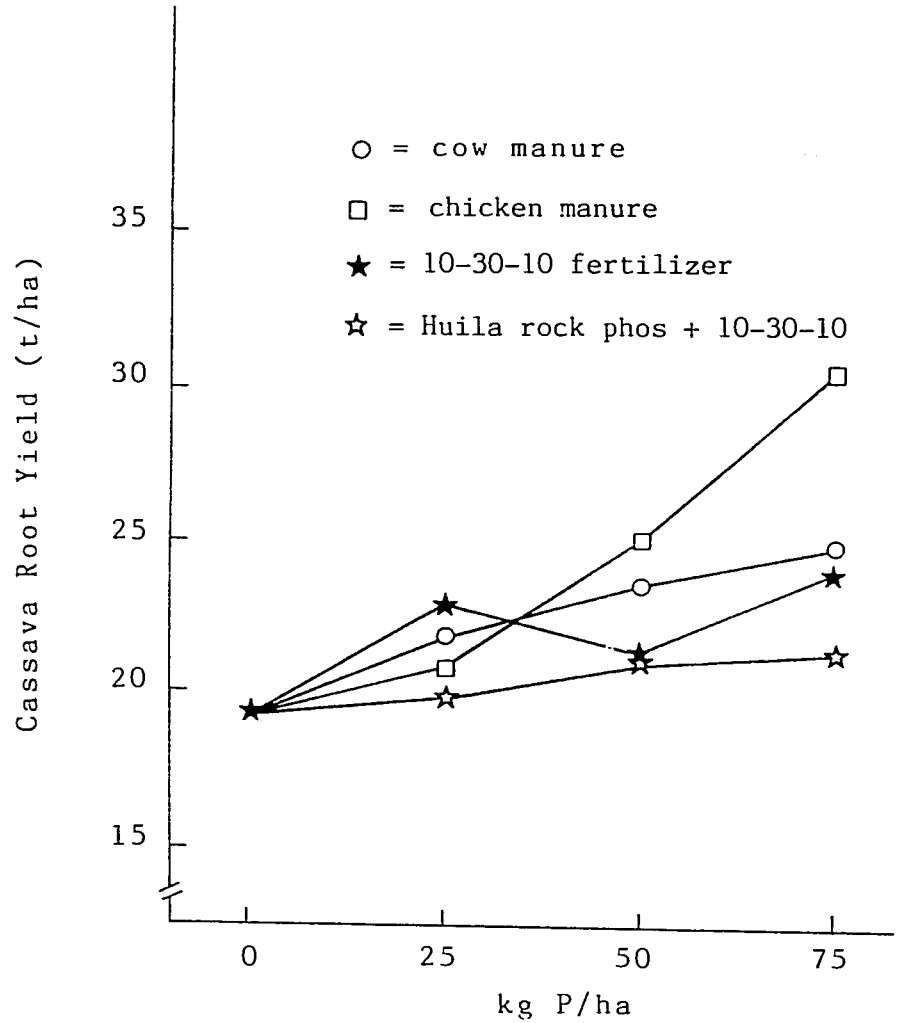

Figure 11. Cassava response to P applied as either organic manures or inorganic fertilizers in Mondomo. Data are average yields of CMC 92 and CMC 40.

MYCORRHIZA PROJECT

In 1984, Mycorrhiza research concentrated on the strategy of mycorrhizal fungi management by field inoculation. The Cassava Annual Report for 1982 demonstrates in a flow diagram, the isolation and testing procedures of mycorrhizal isolates. These procedures were improved and completed as shown in Figure 1. The model of mycorrhizal investigation for the introduction of effective mycorrhizal isolates to a crop in the field can be subdivided in four principle work areas.

(a) Isolation and storage procedures of mycorrhizal fungi.
(b) Testing procedures of mycorrhizal isolates under controlled (greenhouse) conditions.
(c) Inoculum production; field inoculation and testing procedures.
(d) Transfers of mycorrhizal technology to other institutions.

In all areas of the model, research work was conducted.

A. Isolation and Storage of Mycorrhizal Fungi.

At CIAT, the mycorrhizal isolate collection now has more than 420 pure cultures from more than 90 origins in Colombia. Of these isolates 272 are stored in the cold room. Besides numerous undefined species, the collection also contains 30 defined and described species of mycorrhizal fungi of which six are newly described species from Colombia: *Glomus manihotis* , Howeler, Sieverding *et* Schenck; *Acaulospora appendicula* Spain, Sieverding *et* Schenck; *A. longula*, Spain *et* Schenck; *A. mellea*, Spain *et* Schenck; *A. morrowae*, Spain et Schenck; *Entrophospora colombiana* Spain *et* Schenck. The collection will be increased steadily.

B. Evaluation of Mycorrhizal Isolates in the Greenhouse. Effectivity

Evaluation of mycorrhizal isolates for effectivity was carried out to lesser extent than in 1983. The effectivity of 35 isolates in TEST I conditions (without competition from other microorganisms, (see Cassava Annual Report, 1982, 1983) is shown in Table 1.

Of the 103 isolates, tested up to the present time, 41 were found to be highly effective in increasing the growth of cassava (Table 2). These 41 isolates represent 10 mycorrhizal species. Table 2 also shows that tested isolates of *Glomus manihotis* and of a *Glomus* sp., code name "BIM", were generally effective, whereas of the eight other species, the effectivity of an isolate depended on its origin. This indicates that *Glomus manihotis* may be generally characterized as a highly effective species for cassava, the other species may be so specialized as to be highly effective under certain conditions, i.e., the characterization of a mycorrhizal isolate by determination of the species is only possible for a few species. However, a negative prognosis may be possible, as is the case of the genus *Gigaspora* where no tested species and isolates have been effective so far for increasing cassava growth in acid low P content soils.

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Interaction between cassava cultivars and mycorrhizal isolates

The effectivity of different mycorrhizal species with various cassava cultivars was tested in three greenhouse trials, using soil substrates consisting of Quilichao soil mixed with river-sand. In the first experiment the soil had been utilized in a previous experiment where the crop had been fertilized with 100 kg P/ha. Therefore, the P contents in the soils of the three experiments varied, being 21 g P/g of soil (Bray II extractable) in the first experiment and 11 g P/g in the other two at 14 days after fertilization with 50 P/ha as triple superphosphate. Rooted tip cuttings of various cassava cultivars were planted and inoculated with mycorrhizal isolates.

Table 3 shows the shoot dry matter production, two months after planting. Response to mycorrhizal inoculation was about twice as high in the first experiment in comparison to the 2nd and 3rd due to the higher soil P content in the first experiment. The two most effective mycorrhizal species were isolates of Glomus manihotis. In the first experiment the Media Luna isolate was more effective than the one from Quilichao. This differential effectiveness disappeared in the 2nd experiment. In the first experiment, cassava clones with many similarities in their growth habits and morphological characteristics were tested; among these clones no differences in growth were found when inoculated with the same mycorrhizal isolate. Special and differential interactions between cassava cultivars and mycorrhizal species were observed in the second and third experiments, in soil with a lower P content. However, the order of effectiveness was as follows: Glomus manihotis Gigaspora margarita Glomus fasciculatum, in all trials in which these species were tested with the different cassava cultivars. Nevertheless, certain cassava cultivars may have affinity for one mycorrhizal species (eg. M Col 1226 and C-1-1). On the other hand there was little variation in the performance of M Col 700 with different isolates and species.

The specific interactions between cassava cultivars and mycorrhizal species are not well understood and research has to be carried out to define those plant parameters on which these interactions depend. Then it may be possible to pool different cassava cultivars in groups, for which the most effective mycorrhizal species can be determined.

Effect of water stress on mycorrhizal effectivity

A greenhouse trial was conducted with the cassava variety CM 342-170 in Quilichao soil. The soil was fertilized by incorporating 50 kg P/ha as Huila rock-phosphate as well as by application of a nutrient solution with the equivalent of 50 kg N/ha, 50 kg K/ha, 25 kg Mg/ha and 5 kg Zn/ha. In each pot containing 7.5 kg dry soil one cassava stake of 5cm length was planted. At the time of planting a soil-root mixture containing pure mycorrhizal isolates was applied under the stake. Two different water regimes were established by: (a) daily watering of the pots to field-capacity of the soil; and (b) watering to field-capacity of the soil when plants showed first symptoms of water deficiency by leaf drooping (heretofore expressed as wet and dry soil conditions). At each rewatering time, the water loss per pot due to evapotranspiration

was registered. Plants were harvested 2.5 months after planting. The results are shown in Table 4.

Under wet soil conditions the response to inoculation with mycorrhizal fungi was as expected, Glomus manihotis and Entrophospora colombiana being the most effective and Gigaspora heterogama and Glomus fasciculatum were not effective species for total plant dry matter production. The frequency of mycorrhizal roots showed clearly that no correlation exists between plant growth and mycorrhizal root infection, or between these parameters and mycorrhizal spore production. The latter was highest with E. colombiana and A. longula. The water use efficiency (WUE) was strongly related to the plant growth; more plant growth was associated with efficient use of water lost to evapo-transpiration.

Under dry soil conditions, plant growth, P uptake and total root length were not significantly different from those under wet conditions in those treatments, where the dry matter production was small, i.e. with non-inoculated plants and those inoculated with Glomus fasciculatum and Gigaspora heterogama. In all other mycorrhizal treatments, the dry soil condition reduced the growth parameters considerably. Only G. manihotis and E. colombiana increased plant growth in comparison to the non-inoculated plants, under dry conditions. In comparison to wet soil conditions, periods of water stress generally decreased the mycorrhizal spore production. This occurred significantly with A. longula and E. colombiana. Water consumption was significantly less in dry soil conditions with non-inoculated plants. This is understandable because evaporation from the soil surface is considerably reduced under dry conditions. The water consumption per g of dry matter was not significantly different at both water regimes with each mycorrhizal species, except in the case of A. longula, where the water consumption per unit dry matter increased under dry conditions.

In conclusion, the most effective mycorrhizal fungi under both soil water conditions were found to be G. manihotis and E. colombiana. A. longula (CIAT No. C-6-2 , a very common mycorrhizal species in Carimagua) seems to react very sensitively to dry soil conditions by losing its effectivity completely.

Mycorrhizal species by P interaction.

Inoculum production.

A trial greenhouse was conducted to test various mycorrhizal species on their adaptation to P fertilization when the inoculum was placed under the planting material (a similar trial was carried out by the Mycorrhiza Project in 1983, see Cassava Annual Report for 1983) where the inoculum of the utilized mycorrhizal species was mixed with the soil.

In this trial, five levels of P, ranging from 0 to 200 kg P/ha, were applied as ground superphosphate and mixed into a Quilichao soil before pasteurization and placement in 4 kg pots. Rooted plantlets of cassava, M Ven 77, were planted in these pots either without inoculum or inoculated with one of five mycorrhizal isolates. N and K were applied in solution in amount of 400 kg/ha.

Figure 2 shows the growth response to P application and to inoculation. Growth of non-inoculated plants was extremely poor and plants showed clear symptoms of P-deficiency, even with the application of 100 kg P/ha. Only with 200 kg P/ha plant growth improved slightly and deficiency symptoms disappeared. Inoculation with two relatively ineffective species, isolates C-4-8 (Acaulospora sp.) and C-15-2 (A. mellea), plant growth remained poor at low levels of applied P but increased markedly with each additional P application; plants reached their highest, but still sub-optimum, production of dry matter at the highest P application rate. Inoculation with the other isolates improved plant growth at P levels from 25 to 200 kg P/ha, with maximum growth at 100 kg P/ha. However, inoculation with Glomus manihotis, either with the isolate C-1-1 or C-20-2, resulted in more growth than inoculation with C-10 (Entrophospora colombiana), especially at P levels of 25 and 50 kg P/ha. Thus, it is clear that there exists a marked interaction between mycorrhizal species and P application levels.

Spore numbers were generally low without P and increased with increasing P application in isolates C-15-2 and C-4-8, paralleling the increase in dry matter production with these isolates. In case of inoculation with Clomus manihotis (C-1-1 and C-20-2) spore numbers were little affected by P application, except that they decreased markedly with the highest level of P application. Inoculation with C-10 produced up to ten times more spores than in any other species, but spore numbers were little affected by the level of P application. Root infection was significantly higher with the two Glomus manihotis isolates, compared with those of other species, but neither of the isolates showed a consistent effect of P application on percentage of root infection.

C. Field Inoculation and Testing of Mycorrhizal Isolates in the Field.

Multiplication of mycorrhizal isolates for field trials.

There are two principle strategies to supply mycorrhizal inoculum to the farmer:

(1) An inoculum production industry can offer the required material to the farmer, however, this implies product costs and transportation costs for the farmer. These costs will probably only be accepted by the small farmer when the mycorrhizal inoculum amount per hectare can be decreased so that these costs will not represent a major investment relative to the expected benefits of field inoculation.

(2) The second strategy includes the production of large amounts of inoculum on the farm. In this case technology will have to be developed to enable small farmers to produce inoculum with a very small capital requirement. Also, on-farm production will reduce the transportation cost. For on-farm production, farmers will need a cheap and relatively safe soil sterilant, as well as a host plant and a very small amount of starter inoculum with a highly effective mycorrhizal isolate which must be adapted to the edaphoclimatic conditions. By sterilizing a 25 m^2 land area to a depth of 20 cm, inoculation of this area and planting a host plant, the farmer can produce in about 3-4 months five tons of inoculum to inoculate one

hectare of cassava. Thus, research was conducted to look for suitable soil sterilants and host plants.

Soil sterilants

Different treatments were applied to a virgin Quilichao soil to decrease the indigenous mycorrhizal population. With these treated soils (Table 5) a bioassay was conducted, using Pueraria phaseoloides as the test plant. The mycorrhizal frequency in the roots at one and two months after planting was used as an indicator for the effectivity of the sterilation method or the soil sterilizant to eradicate the natural mycorrhizal population.

The indigenous population consisted of Entrophospora colombiana, Glomus occultum, G. manihotis, Acaulospora appendicula , A. longula and A. morrowae; the quantity of each was not defined. The indigenous population infected the bioassay plant roots rapidly increasing over time. Sun drying, or solar heating under a black plastic was not effective in reducing the mycorrhizal frequency. Processes of autoclaving, pasteurizing, heating and application of methyl bromide are all known to erradicate the mycorrhizal population completely, but these methods are not very practical for farmers' needs. Methyl bromide is highly dangerous and should not be recommended for use by farmers. From the commercial soil sterilizants, Basamid and formol (when the soil is covered) appear to be the most effective in inhibiting the native mycorrhiza in the first two months of plant growth. This time would be enough for the establishment of an introduced effective mycorrhizal isolate in the field. Vapam was found to be phytotoxic in the first growth stage, probably due to insufficient aeration time after application of the product. Utilizing Vapam, G. occultum and A. appendicula were found in the soil, two months after planting (MAP). Di-Trapex did not completely inhibit the development of mycorrhiza after one month; up until two months, mycorrhiza occupied one third of the roots. However, with Di-Trapex only A. appendicula was multiplied.

The following conclusion can be drawn from the trial: From the commercial products, Basamid may be the most useful, as apart from being effective it is a granulated product and can be incorporated safely and easily up to a defined depth in the soil. Formol is well-known by small farmers, and maybe better accepted as a soil sterilizant. The results with the other two products indicate that chemical ingredients can erradicate some specific mycorrhizal fungi. This indicates that if the mycorrhizal population in the production area of inoculum is known, and if the product does not erradicate the effective mycorrhizal species, then only by applying a commercial product and planting a useful host, an effective inoculum can be produced, A series of trials will be necessary to confirm this hypothesis.

Host plants

In the search for suitable host plants for mycorrhizal inoculum production in acid, low P soils some aspects must be considered: (1) the plant has to be adapted to the edaphoclimatic conditions; (2) the plant species should not have root diseases in common with cassava; (3) the host plant should be an excellent reproducer of mycorrhizal fungi. Taking these considerations into account, cassava must be excluded as

host plant. For acidic, low P soils, suitable plant species can be found with pasture plants. As shown in Figure 3, pasture legumes can reproduce mycorrhizal fungi to a higher extent than pasture grasses; however, pasture legumes may have root diseases in common with cassava and the species which have been investigated are not adapted to colder climates e.g. edaphoclimatic zone V. Of the pasture grasses, Brachiaria decumbens may be a suitable host plant, taking into consideration the above-mentioned points.

A greenhouse trial was conducted to follow the mycorrhizal spore production with Canavalia ensiformis at three levels of P application over time. The results of spore production at 60, 90 and 120 days after planting are shown in Table 6. Cutting the plant shoots at 90 days after planting reduced the spore production of A. appendicula. With all other species the spore production increased with time. An appropriate P level for the multiplication of most mycorrhizal isolates may be 50 kg P/ha. As was expected, G. manihotis multiplied to an acceptable degree only when P was applied. Of all the species, G. manihotis required the longest time to reproduce. Reproduction rate was highly dependent on the mycorrhizal species. The small-sized species, A. longula , E. colombiana and G. occultum were multiplied in higher amounts than the large-sized species, with one exception, Gigaspora heterogama (CIAT No. C-37-8). In general, C. ensiformis multiplied this species best. This is surprising because the reproduction of the same isolate was small with cassava in the same soil (see "Effect of Water Stress on Micorrhizal Effectivity" in this report). It must be concluded, that C. ensiformis has a high preference for forming a mycorrhizal association with G. heterogama.

Test of mycorrhizal species in the field

The soil and plant nutrition section of the Cassava Program tested seven mycorrhizal species in a farmer's field in Mondomo (a non-eroded soil site, as reported in the Cassava Annual Report for 1983). Cassava, CMC 92, was planted without or with inoculation with 100 g/stake of a soil-root mixture infected with one of seven mycorrhizal isolates. P was either band-applied at 100 kg P/ha as diammonium phosphate (DAP) or incorporated as basic slag. N and K were band-applied at levels of 120 kg and 100 kg/ha, respectively.

Figure 4 shows a rather high yield of 26 t/ha without inoculation and a marked positive response to inoculation with Glomus manihotis (C-20-2, collected in Carimagua), G. occultum (C-12-2) and Entrophospora colombiana (C-10). Inoculation with Acaulospora mellea (C-15-2) and Acaulospora sp. (C-7) had lower positive effects on yields. G. manihotis, the isolate C-1-1 collected in Quilichao, and G. fasciculatum (C-5) had no effect. Last year, the G. manihotis isolate from Quilichao was also non-effective in a similar non-eroded soil close to the site where this trial was conducted. The results show that isolates of G. manihotis, a mycorrhizal species of generally high effectivity for cassava, may differ in their efficiency under certain conditions.

Field inoculation methodology

In last year's Cassava Annual Report it was reported that the most effective method of placement of mycorrhizal inoculum was half of the inoculum under the cassava stake at planting and the other half of the inoculum banded on either side of the plant five months after planting. This was confirmed by one other trial carried out this year (Table 7).

Effect of NPK fertilization on inoculation response

At Carimagua-Acuario, a NPK trial was conducted by the soil and plant nutrition section of the Cassava Program. Cassava, M Ven 77, was planted and either not inoculated or inoculated with 200 g/stake of a soil root mixture infected with Glomus manihotis (C-1-1). Four levels of N, P, K were band-applied in various combinations (Figure 5).

There were marked visual responses to NPK application but little differences in top growth due to inoculation. However, root yields generally tended to be higher in inoculated than non-inoculated plants at the lower fertilizer levels. This effect was most marked at low levels of N and intermediate levels of K application. Without inoculation there was a nearly linear response to N and K application up to 200 kg/ha, while with inoculation there was no response to N, and only a response to 50 kg K/ha. Clearly, high levels of band-applied N and K had a detrimental effect in plants inoculated with C-1-1. However, there was no such effect due to P fertilization, as the inoculated plants produced slightly higher yields at all levels of P application. The results show that: (1) for optimum use of an introduced fungus to the field, a balanced nutrition of the plant by low N and K applications is required; and (2) besides saving P fertilizer by inoculation with an effective mycorrhizal fungus, N and K fertilizer levels can be decreased considerably for obtaining maximum yields.

Persistence of mycorrhizal inoculation effect

Field trials inoculated in 1982 were replanted after harvest in 1983. At Pescador (Figure 6) 50 kg P/ha were applied, either as diammonium phosphate (DAP) or Huila rock phosphate (HR). N and K were applied at 25 kg/ha. In general, fresh root yields increased from 1983 to 1984 (each one year growth cycle), especially with cassava which was not inoculated in the first year and which was fertilized with Huila rock phosphate. The most effective mycorrhizal species last year, were also effective this year. However, with a 2 t/ha fresh root yield increase, the residual effect of field inoculation was much smaller than the initial effect. Inoculation of the field with G. occultum initially, together with DAP application in the second year considerably decreased the yields in the second year. The same species was, however, the most effective at increasing yields with Huila rock phosphate as the P source. This may indicate that to maintain the inoculation effect in the field, fertilization practice can play an important role.

At Agua Blanca, two trials were replanted and 25 kg P/ha were applied as DAP; N was applied at a rate of 25 kg/ha and K at 50 kg/ha. The most effective mycorrhizal isolates in 1983 were not harmful for yields in 1984 (Table 8). However, at site A, the initial inoculation (with the mixture of G. manihotis E. colombiana) reduced the yield in

the second year. This may be related to the fact that G. manihotis requires higher P application to be effective in the field.

D. Transfer Of Mycorrhizal Technology.

In February 1984, together with the Faculty of Agriculture of the National University of Colombia, in Palmira, the "First National Colombian Course on Mycorrhiza" was organized. A separate report about the course is available at the mycorrhiza project office at CIAT or at the Faculty of Agriculture in Palmira.

Table 1. Evaluation of mycorrhizal isolates' effectivity for cassava in Test 1.

Isolate no.	Species code	Effectivity in soil for			
		Dry matter	P uptake	Root length	Root infection
C-1-1	MAN	xxx[a]	xxx	xx	xxx
C-2-3	LON	x	x	x	x
C-2-4	OCC	xx	xx	xxx	x
C-2-6	OCC	x	x	xx	xx
C-3-2	OCC	xxx	xxx	xxx	x
C-3-4	007	xxx	xxx	xxx	xx
C-3-10	MAN	xxx	xxx	xx	xxx
C-3-11	COL	x	x	xx	xxx
C-3-12	MOR	0	0	0	x
C-3-14	FOV	xx	xx	xxx	xx
C-3-15	LAE	x	xx	0	xxx
C-3-17	MOR	x	0	x	x
C-9	HET	0	0	0	0
C-11-3	OCC	xx	xx	xxx	x
C-13-3/4	BIM	xxx	xxx	x	xxx
C-13-5	COL	xx	xxx	x	xxx
C-13-6	LON	xxx	xxx	xxx	xxx
C-13-8	OCC	xx	xx	xxx	xx
C-17-3	007	xxx	xxx	x	xxx
C-78	MAN	xxx	xxx	xx	xxx
C-82	MAN	xxx	xxx	xx	xx
C-85	APP	xxx	xxx	xxx	xx
C-86-2	LAE	xxx	xxx	xx	xxx
C-88-1	007	x	xx	0	x
C-88-2	Unident.	0	0	x	0
C-89-1	PEL	x	xx	x	x
C-89-2	LAE	0	0	xxx	xxx
C-89-3	MOR	0	0	0	xx
C-90-1	APP	0	xx	x	x
C-90-2	COL	xx	xx	xxx	x
C-92-1	OCC	x	xx	0	0
C-92-2	OCC	xxx	xx	xxx	x
C-93-1	MEL	0	0	0	x
C-93-2	LON	x	x	0	xxx
C-105	Glomus sp.	xxx	xx	xx	xx

[a]0 = not effective; x = low effectivity; xx = medium effectivity; xxx = high effectivity.

Table 2. Effectivity of isolates of some mycorrhizal species.

Species	Total no. of isolates tested	No. of highly effective isolates	No. of highly and moderately effective isolates
Glomus occultum	20	5	13
Acaulospora longula	14	6	8
Entrophospora colombiana	11	8	10
Glomus manihotis	10	10	10
Acaulospora appendicula	5	3	4
Acaulospora sp. "007"	5	4	5
Acaulospora laevis	3	1	1
Glomus sp. "BIM"	2	2	2
Glomus microcarpum	2	1	2
Acaulospora foveata	2	1	2
Total	74	41	57

Table 3. Effect of mycorrhizal isolates on shoot dry matter production of cassava cultivars in three experiments; P content of the Quilichao/sand mixture was 21 g P/g of soil, in the first experiment, and 11 g P/g in the second and third experiment.

Cassava cultivar	NM[a]	Mycorrhizal isolates[b] C-1-1	C-17-1	C-18-1	C-19-1	C-21
M Ven 77	0.64	7.38	9.24	5.09	-	6.09
M Col 1914	1.56	6.78	9.67	5.05	-	6.73
M Ec 82	0.51	7.74	8.65	3.92	-	5.46
M Pan 12-B	0.41	7.74	8.44	4.20	-	5.86
	LSD 5% (all groups): 1.49					
M Ven 77	0.28	3.99	4.06	0.83	-	0.64
M Bra 22	0.55	3.99	4.11	1.35	-	2.78
M Pan 12-A	0.55	5.15	4.65	0.98	-	2.15
M Pan 51	1.38	5.53	5.62	1.81	-	3.73
	LSD 5% (all groups): 1.72					
M Ven 77	0.40	3.94	-	1.07	5.18	1.93
M Col 700	0.40	3.37	-	1.62	4.22	3.05
M Col 1226	0.54	8.83	-	3.09	6.88	4.05
M Col 1488	0.16	6.62	-	3.74	5.86	3.86
CM 440-5	0.10	6.71	-	3.13	6.20	4.16
	LSD 5% (all groups): 1.44					

[a] Plants grown without mycorrhiza.

[b] C-1-1 = Glomus manihotis (Quilichao); C-17-1 = Glomus manihotis (Media Luna); C-18-1 = Glomus fasciculatum (Agua Blanca); C-19-1 = Glomus microcarpum (Agua Blanca); C-21 = Gigaspora margarita (Rothamsted, England).

Table 4. Effect of soil water conditions on the effectivity of mycorrhizal species with the cassava variety CM 342-170 in pasteurized Quilichao soil.

Mycorrhizal species[a]	Total DM g/plant	P uptake in shoot mg/plant	Total root length m/plant	Mycorrhizal infection %	Mycor. spore no./100g soil	WUE[b] ml H_2O/ g DM
Wet conditions						
Not inoculated	8.9^{h}	2.4^{e}	18.9^{de}	0.0^{g}	0^{e}	1085^{a}
G. manihotis	84.3^{a}	45.4^{a}	198.8^{a}	80.3^{b}	2714^{cd}	238^{g}
G. fasciculatum	12.6^{gh}	5.9^{cde}	49.7^{cde}	73.0^{bcd}	150^{d}	904^{ab}
G. occultum	43.2^{c}	46.8^{a}	154.5^{b}	78.2^{bc}	790^{d}	416^{fg}
Gi. heterogama	14.1^{gh}	3.9^{de}	29.5^{de}	7.5^{g}	12^{d}	715^{bcd}
A. longula	29.8^{de}	21.6^{bc}	158.8^{b}	63.7^{de}	21208^{b}	441^{fg}
Acaulospora sp. "007"	35.1^{cd}	33.1^{ab}	206.2^{a}	8.1^{g}	3900^{cd}	393^{fg}
E. colombiana	71.4^{b}	45.8^{a}	205.8^{a}	61.6^{de}	31265^{a}	246^{g}
Dry conditions						
Not inoculated	8.8^{h}	2.3^{e}	17.6^{e}	0.0^{g}	0^{e}	752^{bc}
G. manihotis	21.6^{efg}	27.3^{b}	82.1^{c}	97.8^{a}	350^{d}	416^{fg}
G. fasciculatum	12.9^{gh}	5.2^{de}	30.4^{de}	52.9^{e}	83^{d}	712^{bcd}
G. occultum	19.2^{fgh}	19.6^{bcd}	45.7^{cde}	66.5^{cd}	325^{d}	478^{ef}
Gi. heterogama	9.7^{h}	3.0^{e}	24.6^{de}	8.9^{g}	48^{d}	770^{bc}
A. longula	9.5^{h}	3.5^{de}	24.3^{de}	36.7^{f}	292^{d}	669^{cde}
Acaulospora sp. "007"	14.9^{fgh}	7.4^{cde}	60.5^{cd}	11.8^{g}	94^{d}	515^{def}
E. colombiana	25.0^{def}	25.8^{b}	77.6^{c}	66.2^{cd}	5600^{c}	399^{fg}

[a] *Glomus manihotis* (CIAT No. C-1-1); *G. fasciculatum* (C-18-1); *G. occultum* (C-19-3); *Gigaspora heterogama* (C-37-8); *Acaulospora longula* (C-6-2); *Acaulospora* sp. "007" (C-7); *Entrophospora colombiana* (C-10).

[b] WUE = water use efficiency (evapotranspiration) per g DM

Table 5. Efficiency of soil sterilants and methods for the eradication of the indigenous mycorrhizal population in a Quilichao soil; bioassay was conducted with *Pueraria phaseoloides*.

Treatment	Mycorrhizal infection potential	
	1 MAP[a]	2 MAP
Untreated	49.1	55.0
Sun dried	43.0	44.1
Solar heated under black PVC plastic	43.7	40.1
Pasteurized	0.0	0.0
Sterilized with methyl bromide	0.0	0.0
Autoclaved	0.0	0.0
Heated in can above open fire	0.0	0.0
Vapam (150 cm^3/m^2)	0.0[b]	43.2
Basamid (50 g/m^2)	0.0	3.1
Di-Trapex (60 cm^3/m^2)	6.6	33.8
Formol (150 cm^3/m^2), uncovered soil	0.0	30.7
Formol (150 cm^3/m^2), covered	0.4	0.7

[a] MAP: Months after planting.
[b] Plants were affected by toxicity of the product.

Table 6. Spore production (number/100 g dry soil) of several mycorrhizal species with *Canavalia ensiformis*, at different levels of P application in Quilichao soil (without lime) at 60, 90 and 120 days after planting.

Mycorrhizal species[a]	60 days after planting kg P/ha			90 days after planting[b] kg P/ha			120 days after planting Kg P/ha		
	0	50	100	0	50	100	0	50	100
A. longula	251	446	3272	3782	304	[c]	23214	13795	1968
A. appendicula	15	879	176	55	404	1153	113	195	123
E. colombiana	2560	2411	7343	1562	9391	5785	3339	16143	18147
Gi. heterogama	2167	6890	7799	7994	16494	12354	9633	23272	16662
G. manihotis	75	0	0	5	643	289	0	2011	494
G. occultum	319	1454	1380	1321	16640	7956	1802	13994	13223

[a] *Acaulospora longula* (C-13-6); *A. appendicula* (C-27-3/4); *Entrophospora colombiana* (C-10); *Gigaspora heterogama* (C-37-8); *Glomus manihotis* (C-1-1); *G. occultum* (C-1-3).

[b] At 90 days after planting, shoots were cut.

[c] Data lost.

Table 7. Effect of mycorrhizal inoculum placement on cassava fresh root yield in the field (Mondomo, Cauca) (50 kg P/ha were incorporated as Huila rock phosphate, in these trials).

Inoculum placement method	1984 trial (mean of 8 repl.) t/ha	Average 1983 trials (2) and 1987 trial t/ha
Not inoculated	13.5	15.3
Inoculum placed under the stakes	16.9	16.7
Half of inoculum placed under stakes at planting and half in side bands, 5 MAP[a]	21.0	19.5

[a] MAP = months after planting.

Table 8. Residual effects of field inoculation on cassava fresh root yields at two trial sites in Agua Blanca, Cauca; fields were inoculated in 1982 at planting of cassava.

	Fresh root yields (t/ha) at harvest	
	1983	1984
Site A		
Not inoculated	24.7	22.1
Inoc. C-1-1/C-10	27.8	19.8
Inoc. C-3-5	31.1	22.4
Site B		
Not inoc.	21.2	12.6
Inoc. C-1-1/C-10	27.1	14.2
Inoc. C-3-6	24.2	12.0

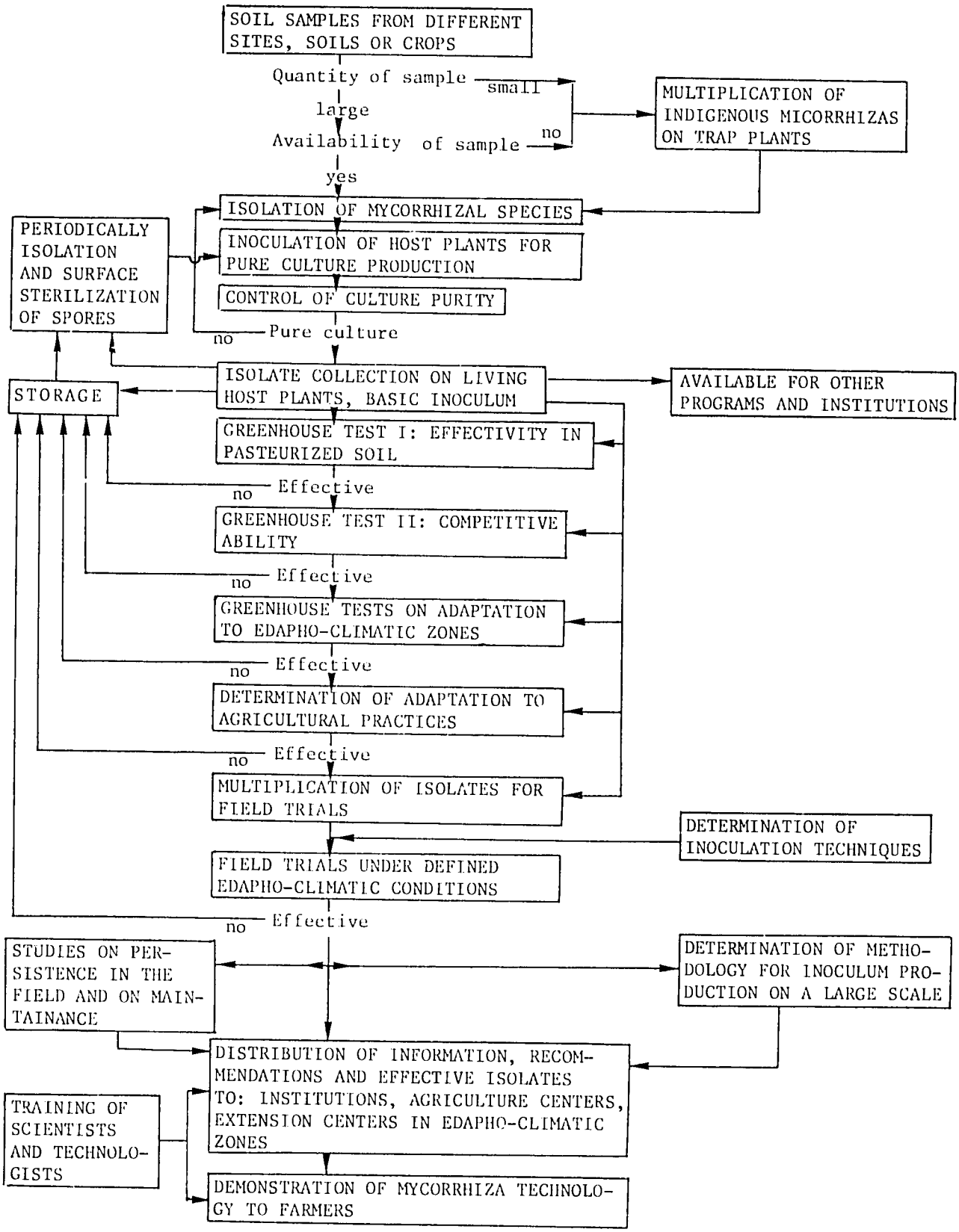

Figure 1. Flow diagram for mycorrhizal research in the Mycorrhiza Project (1984); strategy of managing mycorrhizal fungi by field inoculation.

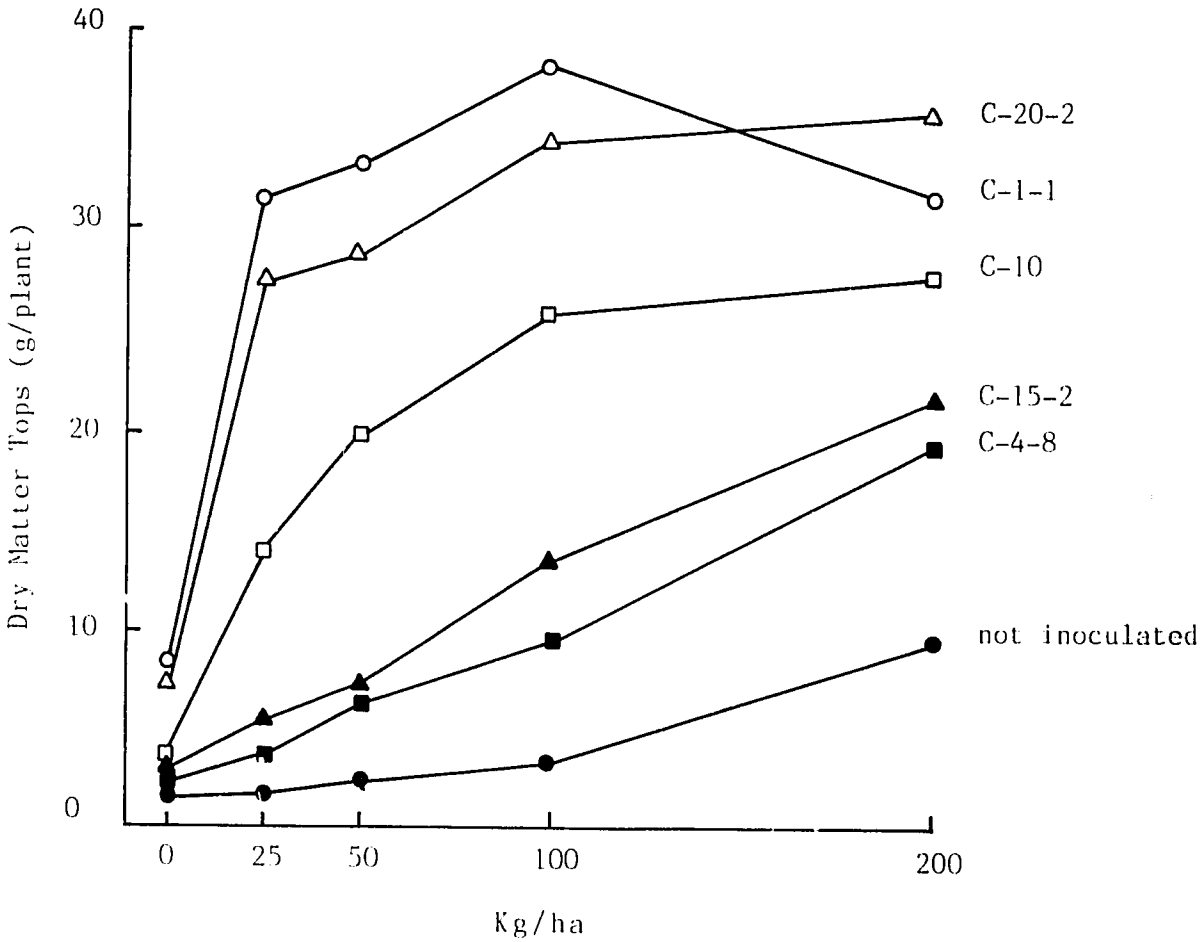

Figure 2. Dry matter response of cassava, M Ven 77, to application of various levels of P and inoculation with five mycorrhizal strains in sterilized Quilichao soil.

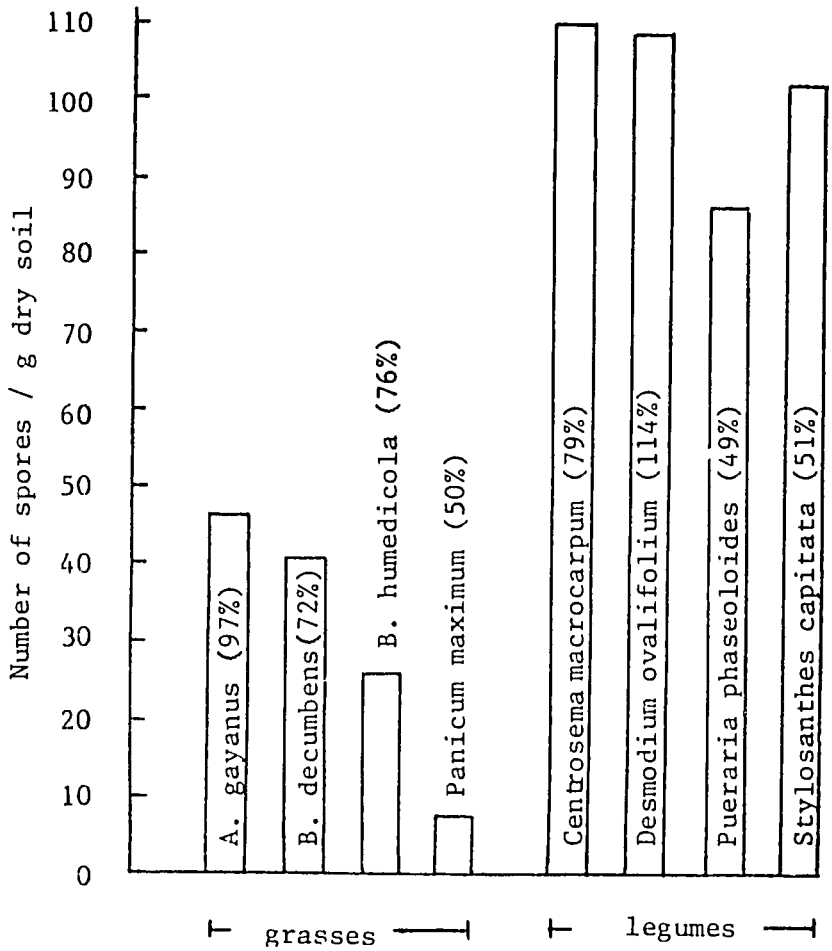

Figure 3. Effect of host plants on mycorrhizal spore production; in parenthesis the coefficient of variability due to six different levels of P applications.

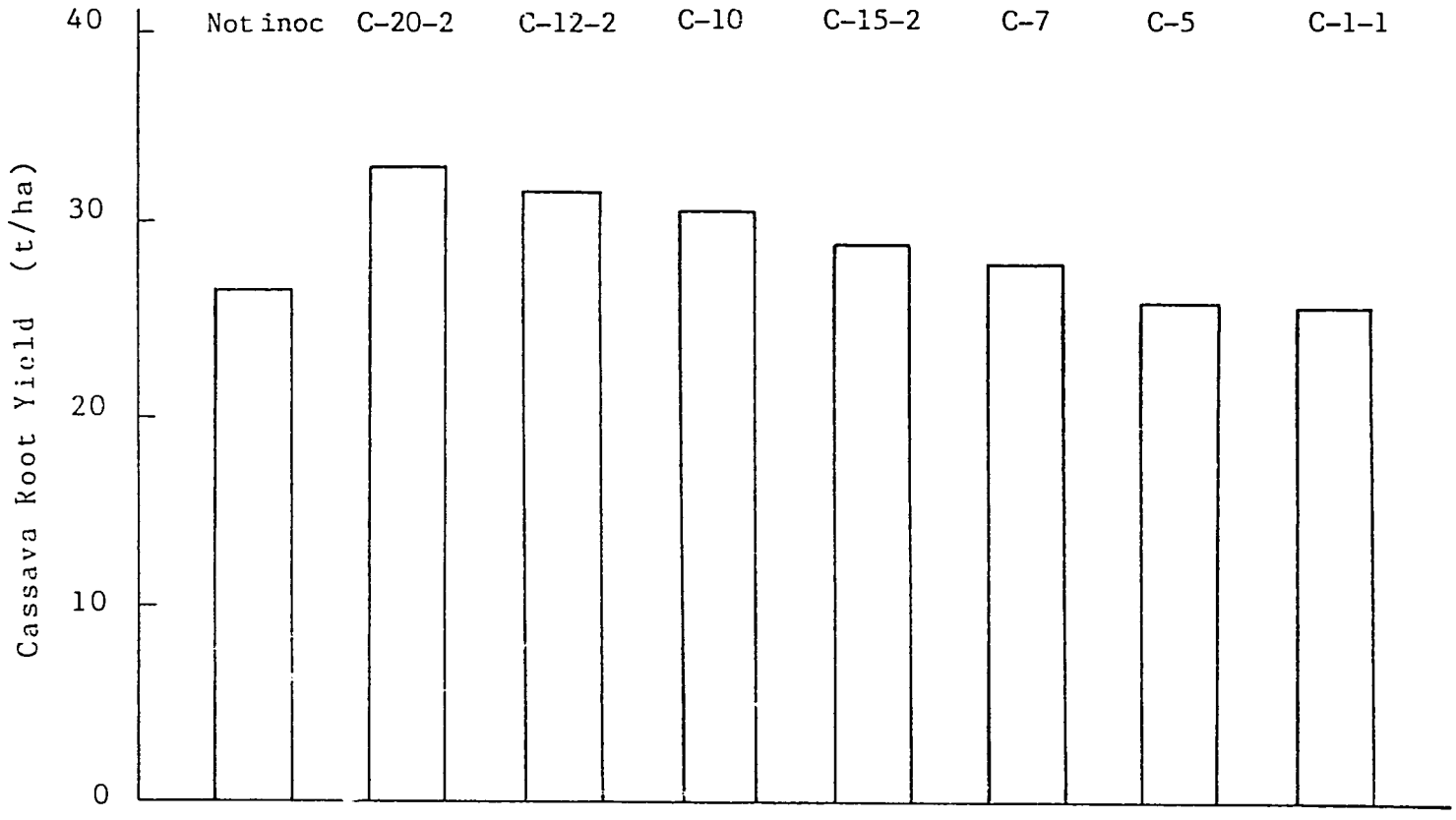

Figure 4. Average response of cassava, CMC 92, to inoculation with seven mycorrhizal isolates in Mondomo, in plots fertilized with 100 kg P/ha as DAP or basic slag.

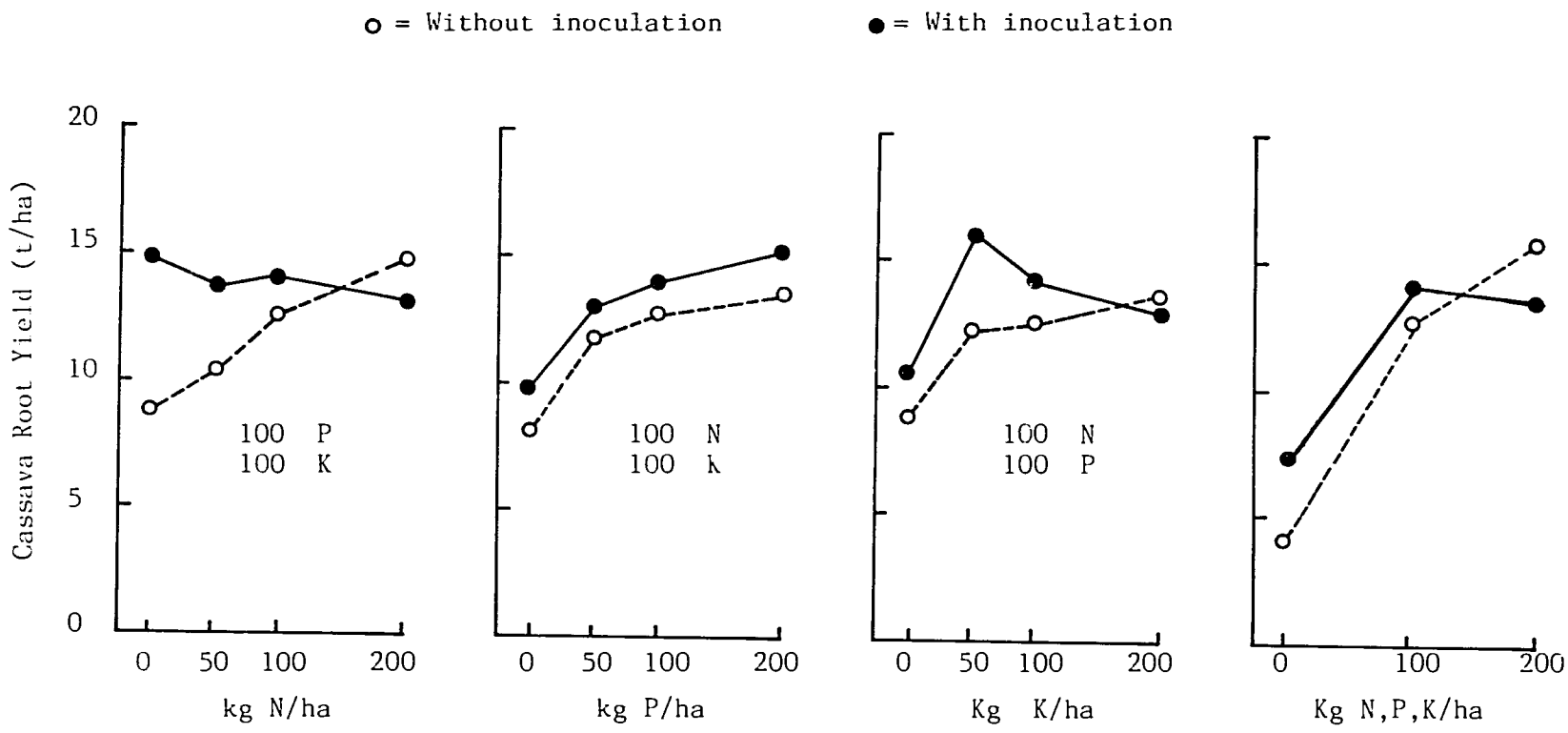

Figure 5. Response of cassava, M Ven 77, to application of N, P and K with or without inoculation with mycorrhizal strain C-1-1 in Carimagua.

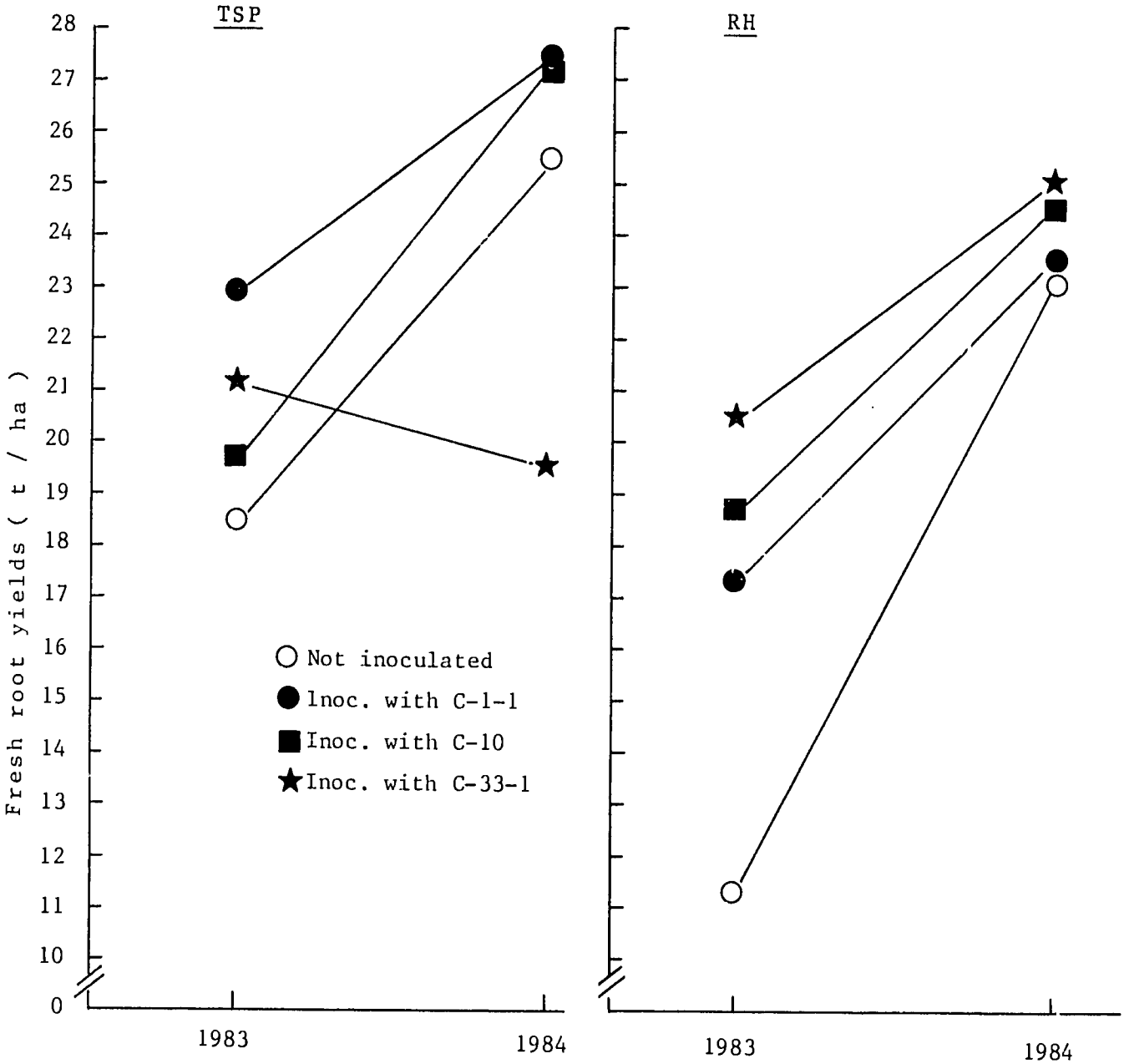

Figure 6. Effect of field inoculation with mycorrhizal species (C-1-1: Glomus manihotis; C-10: Entrophospora colombiana; C-33-1: G. occultum) at planting, 1982, on the cassava root yields in the first (1983) and second (1984) year, when soluble (TSP) or rather unsoluble (RH) P sources were applied.

PATHOLOGY

Anthracnosis

This is one of the most important diseases during the rainy season in most growing areas, inducing severe defoliation, dieback and stem cankers, and decreasing the quality of planting material produced by affected plants. Since the information available on this disease and the causal agents are very limited an investigation related to disease etiology and the epidemiology of the disease was initiated to gain information for further studies on genetic resistance.

Seventy-six *Colletotrichum* isolates were collected from different susceptible clones from eight localities. Eleven groups of these isolates were distinguished based on: conidia morphology, production and acervuli characteristics including color, shape, location and distribution on host-tissue; mycelial type and color; *in vitro* production of the sexual stage, and characteristics of the sexual fruiting body including color, shape and distribution of asci and ascospores. Four of these groups were specific to cassava, but seven also attacked other host species. Taxonomically these groups appear to belong to *Colletotrichum gloeosporioides*, f.s. *manihotis*, *C. gloeosporioides*, and *C. graminicola*.

Six inoculation methods were tested, but the only satisfactory method was the one where the plant tissue was wounded before conidial spraying (conidia suspension in distilled water of 1×10^6 conidia/ml). This indicates the facultative parasitic nature of *Colletotrichum* and its association with mechanical or biological agents that might injure the host plant tissue before infection is possible. The identification of such agents in each ecosystem is important to determine the appropriate strategies of control.

Based on the reaction of six differential cassava clones, two pathovars were distinguished in *C. gloeosporioides* f.s. *manihotis* and three in *C. gloeosporioides* groups (Table 1). This indicates the variability of the *Colletotrichum* and the possible existence of a genetic interaction between pathogen and host.

Fusarium Root Rots

Even though cassava root rots can be induced by more than 25 causal agents, *Fusarium* spp. are the most common and prevalent in several cassava growing areas. Serious economic losses have been reported in Tuxpan, Mexico (Texas rot/la Pudricion Texana), Brazil, and Colombia. Affected plants are initially light yellow and then suddenly defoliate due to total rotting of the root system. Swollen roots are watery and macerated, causing a total yield loss. The disease initially appears on a few scattered plants, but a few days later neighboring plants also become affected and the infection gradually expands until the whole plantation is affected if the clone is susceptible and the pathogen aggressive.

Two species of *Fusarium* (*F. solani* and *F. oxysporum*) have been isolated from different affected regions and characterized according to phialide and conidial morphology, and cultural characteristics on several differential media. Soil inoculated plants (10 ml of a suspension of 1 x

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10^6 conidia/ml/plant) induced plant death 40 days after inoculation, but some plants were not affected. Ten cm terminal shoots were cut from 20 cm sprouts on a susceptible clone and placed in a similar conidial suspension; all plants died within 20-25 days. Following the same inoculation method, inoculated shoots of three clones showed different reactions in relation to the Fusarium spp. inoculated. The development of a mass resistance screening technique using the above inoculation method is underway.

Effect of the Antholysis Disease on Yield

Antholysis is a mycoplasmal disease with symptoms mostly restricted to the floral structures of affected plants (Cassava Annual Report, 1983). The effect on yield was evaluated on the susceptible clone Secundina by planting randomized plots (30 cuttings/plot) of clean and diseased cuttings at Media Luna [mean temperature of 28°C with a three month dry period (maximum = 39°C, minimum = 20°C)] and at CIAT [with mean temperature of 24°C (maximum = 32°C and minimum = 16°C)].

Clean planting material was obtained from plants derived from meristem cultures and diseased cuttings were obtained from initially clean scions grown on diseased stalks for approximately seven months after grafting until characteristic symptoms of antholysis were noticed. At CIAT, (a cool environment) plants from affected cuttings exhibited characteristic antholysis symptoms, were significantly stunted and yielded approximately 48% less than plants from healthy cuttings (Table 2). However, at Media Luna (a warmer environment) plants from affected cuttings were symptomless and yield was not reduced. These results suggest that in areas where average temperatures are above 27°C the disease might not be of economic importance; however, in areas with an average temperature below 25°C the disease can be of significant importance requiring control measures by the use of clean planting material.

Control of Root Rots

The production of cassava is commonly reduced by microbial root rots in many cassava growing areas. Several measures to control these problems have been reported previously, such as planting on ridges (Cassava Annual Report, 1973), elimination of plant residues (Cassava Annual Report, 1978), stake treatments with fungicides and pesticides (Cassava Annual Reports 1978,79 and 80), and crop rotation (Cassava Annual Reports, 1974 and 1983). However, due to climatic, edaphic and microbial interactions the problem is very complex and in some situations the reported control measures are not successful in all ecosystems. Two new systems to control root rots have been recently investigated with satisfactory results.

Biocontrol of root rots

Last year's report dealt with the effect of Pseudomonas putida and P. fluorescens on cassava clones under greenhouse conditions. This year, preliminary results from field experiments at Carimagua showed that the yield of cassava roots can be increased in some cases by inoculation with some strains of P. putida; however, in other cases yield was decreased. These results indicate the need for more research on pseudomonas

fluorescent inoculations before any conclusion about its effectivity can be reached (Table 3).

Solarization

Plastic sheets were used to cover 30 m^2 plots for periods of 15 and 30 days prior to planting the clone CMC 40. Data were taken on microbial control due to the treatment as well as its effect on yield 11 months after planting. Maximum temperature in the first 5cm layer of soil was 62°C for daily periods ranging from 2 - 5h during the treatment. General microbial populations were reduced approximately two fold (Table 4); generally fungal and bacterial species with low sensitivity to solarization were those able to produce resistant structures (sclerotia, chlamydospores, bacterial spores, etc.) such as species of *Fusarium* and *Bacillus*.

Yield after treatment was significantly increased by 15 and 30 days of solarization and the number of weedings necessary for satisfactory maintenance during the growing cycle was reduced from 3 to 1 (Table 5). The approximate costs of the plastic treatment were estimated as follows: plastic sheet cost US$ 450/ha and installation costs were estimated at US$ 25/ha. The savings of reduced hand weedings (2) were estimated at approximately US$ 100/ha giving a net marginal increase of costs of US$ 375/ha. In the case of 30 day treatment, the marginal yield increase was 11.4 t/ha, or an average marginal cost of about US$ 33/t. Additionally harvested roots from treated plots were of much better quality than those of the controls due to the effect of solarization on *Stemonitis axifera* (Table 6), a fungus that infects the epidermis of cassava root producing an unacceptable root appearance and root rots if the root epidermis is injured. Similarly, results showed that both broad leaf and gramineous weeds were significantly controlled by 30 days of solarization (Table 7).

Biocontrol of Foliar Pathogens of Cassava

Pseudomonas putida (strain Pp 64) was also used to spray three clones with different levels of resistance to *Xanthomonas campestris* pv. *manihotis*, the causal agent of cassava bacterial blight (CBB). Results showed that both angular leaf spots and leaf blight were significantly reduced by *P. putida* foliar inoculum (Table 8). Additionally, it was found that the incidence of *Elsinoe brasiliensis*, the causal agent of superelongation disease, was also reduced significantly on both susceptible and intermediate resistant clones (Table 8). These results suggest for the first time the possibility of using fluorescent pseudomonads to control foliar bacterial pathogens, particularly CBB.

Cutting Selection

The selection criteria for cuttings of high quality were evaluated considering agronomic, sanitary and varietal factors. The effect on yield of three selection and treatment criteria are reported here.

Selection of cuttings according to their sanitary appearance and a pre-planting pesticide treatment

Results have shown that when cuttings are visually selected for absence of disease injury and then treated with fungicides and insecticides, high yields can be obtained. The visual selection at CIAT,

where disease presence is low, is more important than the pesticide treatment for yield increase (Table 9).

Selection of cuttings according to yield/plant in a given plantation.

In 1983, plants of four different clones grown on the same plantation were grouped into high and low yielding categories according to whether they yielded above or below the yield average for the clone. A range of approximately 30-70% of the plants yielded above the plantation average. Even with about 30% of the plants yielding above the plantation average it is possible to obtain sufficient high quality planting material. In 1984, cuttings were then taken from these two groups and planted in randomized plots (30 plants/clone/plot) replicated six times. This selection system was tested at three different locations and with different clones at each location. Results at Media Luna, Carimagua, and CIAT (Table 10), demonstrated that by selecting cuttings from plants with a higher yield than the clonal average there was a considerable increase in the number of plants with higher yields than the general clonal average .

In contrast, a significant percentage of the plants grown from cuttings selected from plants in the low yield group yielded less than the clonal average. Plots of cuttings from plants with higher yields than average yielded significantly more than those plots of cuttings with lower yields than the average (Table 11). This indicates that it is possible to increase yields by positive selection of cuttings from plants with higher yields.

Selection of cuttings from plants grown on the most fertile soils of a given farm.

At Carimagua, a station with soils of low fertility, plots of a resistant (M Ecu 82) and an intermediate resistant (CMC 40) clone were planted on the best soils available at Agronomia and Reserva, the latter a location with infertile soils. Results showed that plants of both clones from cuttings of plants grown on the most fertile location had higher yields and lower disease (CBB and Superelongation) ratings than plants from cuttings of plants grown on the unfertile location. Plants from treated cuttings (Orthocide-Benlate mixture) yielded significantly higher than plants from untreated cuttings of both clones (Table 12).

This contrasts with results from CIAT and indicates that for the high disease pressure site, Carimagua, where stake treatment is essential for high yields and also that the quality of cuttings is also highly influenced by the nutritional conditions where the mother plants were grown. In any farm, cuttings should be taken from plants grown on the most fertile plots or special nutritional care should be given to those plots assigned for the production of planting material.

Clonal Stability

The performance of Secundina, a native clone from the North Coast of Colombia, showed a continuous yield decrease after four consecutive planting cycles with planting material taken from plants which originated from meristem culture. Yields after the fourth cycle were similar to the

uncleaned control. In contrast, the hybrid CM 342-170 showed better yield stability over the same number of cycles and location (Table 13). This may indicate that by breeding appropriate genotypes clonal stability can be improved.

Ecosystem Study

Experiments related to these studies were terminated after five years of evaluations of five different localities (see Cassava Annual Reports, 1978 to 1983). The incidence and severity of diseases and pests and the production of fresh roots, starch and stakes are presented in Tables 14 and 15. The interaction between ecosystems and yield, starch content., number of stakes, deterioration, HCN content and harvest index is given in Table 16. A general analysis of the results obtained from these studies leads to the following general conclusions:

(1) Disease and pest incidence and/or population varied between ecosystems and years. The presence and severity of diseases and pests were highly dependent on specific climatic and/or edaphic characteristics that restrict them to the ecological zones where they were found.

(2) Even though there were some positive correlations between sites for several evaluated parameters, differences among the sites were significant. Yield, disease and pest reaction, and number and quality of cuttings were significantly different between sites for the introduced clones.

(3) Reactions of groups of unimproved clones taken from contrasting edapho-climatic sites and from similar edapho-climatic sites showed that the native clones generally possessed the highest levels of resistance to the limiting factors existing in each site. No clones were resistant to the biotic constraints present in more than two edapho-climatic sites.

(4) Great variations during the different growing cycles in each location were observed among several clones; however, some clones from each edapho-climatic site exhibited yield stability over time.

The identification of pathological problems and their severity on cassava production at different sites was initiated by the evaluation of several genotypes under regional trials. Maximum disease severity (1= lowest, and 5= highest) for each disease/site is given in Table 17. Pathological stresses on cassava tended to be location specific. It is hoped that after several cycles of continuous evaluation a better assessment of the severity of disease problems can be determined enabling the development of effective control strategies.

Table 1. Reaction of 24 isolates of *Colletotrichum gloeosporioides* f.s. *manihotis* (*C. g. manihotis*) and 50 isolates of *C. gloeosporioides* on six cassava differential clones 20 days after inoculation (petioles were injured with a sterile needle before inoculum (1×10^6 conidia/ml) was sprayed.

Pathogen species and taxonomic group number	Pathogenic similarity	Average reaction/differential clone					
		M Col 1684	CM 305-120	CMC 92	M Col 420	M Col 113	M Col 2059
C. g. manihotis							
I (4)[a]	A[b]	4[c]	3	3	3	5	5
IV (2)	B	3	3	3	2	2	2
VI (9)	B	3	2	2	3	2	3
XI (9)	A	4	3	2	3	5	4
C. gloeosporioides							
II (8)	A	3	3	3	3	2	2
III (7)	B	4	3	2	3	3	2
V (8)	C	4	3	4	3	2	4
VII (2)	A	3	3	2	3	3	2
VIII (10)	B	4	3	2	3	3	2
X (15)	C	4	4	4	3	3	4

[a] In parentheses are the number of isolates inoculated/taxonomic group.

[b] The same letters represent a similar pathogenic reaction on different clones.

[c] Average reaction of 10 plants/clone/isolate inoculated: 1=no symptoms; 5= plant death.

Table 2. Effect of the Antholysis disease on yield at two different edaphoclimatic areas.

Planting material[a] (Clone Secundina)	Location	
	CIAT yield (t/ha)	Media Luna yield (t/ha)
Treated	36.1a[b]	19.3a
Diseased	17.2b	22.6a

[a] Treated = cuttings from plants derived from thermotherapy and meristem culture; Diseased = cuttings from plants with severe Antholysis symptoms.

[b] Data taken from four replicated plots of 36 plants each. Numbers followed by the same letter are not significantly different at a 0.5 level of the Duncan Multiple Range Test.

Table 3. Yield of five cassava cultivars inoculated with three strains of *Pseudomonas putida* at Carimagua.

Strain number of *P. putida*	Fresh root yield (t/ha)/inoculated cultivar[a]				
	M Col 1914	M Col 1916	M Pan 19	M Pan 12B	M Ven 77
Pp. 64	15.8 (+44)b[b*]	11.2 (+2)	8.3 (-21)	6.2 (-50)	10.3 (-7) c
Pp. 44	15.0 (+36)b	8.9 (-23)	12.5 (+19)	6.4 (-44)	11.8 (+6) b
Pp. 61	12.5 (+14)a	11.8 (+ 7)	11.0 (+ 5)	11.4 (0)	12.4 (+11) b
CK	11.0[a]	11.0	10.5	11.4	11.1 b

[a] Each cultivar received two monthly inoculations at one and two months after planting. Cuttings were also treated by deep inoculation. Inoculum per plant = 10ml of a bacterial suspension of 1×10^9 cells/ml, approximately.

[b] Data taken from six replicates of 30 plants/treatment. The percentage yield increase of each clone/inoculated strain is in parentheses.

* Numbers followed by the same letter are not significantly different at a 0.5 level of the Duncan Multiple Range Test.

Table 4. Microbial population of soils after solarization with a plastic sheet.

Days of solarization	Number of colonies[a]/of soil	
	Fungal	Bacterial
0	4.4×10^6	6.0×10^8
15	1.1×10^5	1.9×10^7
30	6.7×10^4	1.1×10^6

[a] Fungal colonies were isolated on potato dextrose agar containing streptomycin and chlorotetracycline. Bacteria were planted out on nutrient agar.

Table 5. Effect of solarization on cassava yield.

Days of solarization	Fresh root yield (t/ha)[a]	Increase (%)	Number of weedings necessary/cycle
0	18.2 a*	-	3
15	21.7 b	19.2	1
30	29.6 c	62.6	1

[a] Data taken from three replicated plots of 30 plants/treatment.

* Numbers followed by the same letter are not significantly different at the 0.05 level of the Duncan Multiple Range Test.

Table 6. Effect of solarization on percentage of *Stemonitis axifera*-infested roots.

Days of solarization	Infested roots (%)
0	35.4a*
15	20.2b
30	10.6c

* Numbers followed by different letters are significantly different at the 0.05 level of the Duncan Multple Range Test.

Table 7. Average number of weeds (broad-leafed and gramineous) per $36m^2$ plots after 0, 15 and 30 days of solarization with a plastic sheet.

Days of solarization treatment	Data collected 15 days after treatment [a]		Data collected 30 days after	
	Number of broad-leaf plants/plot	Number of gramineous plants/plot	Number of broad-leaf plants/plot	Number of gramineous plants/plot
0	35.7 a*	3.0 a	522.4 a	1.423.0 a
15	0.6 b	1.0 a	15.0 b	4.4 b
30	2.0 b	1.2 a	5.0 b	9.5 b

[a] Data taken from four replicated plots/treatment.

* Numbers followed by the same letter are not significantly different at the 0.05 level of the Duncan Multiple Range Test.

Table 8. Control of cassava bacterial blight (CBB) and the superelongation disease (SD) with foliar application of *Pseudomonas putida*.

Disease	Scoring system	Treatment	Cultivar[e]		
			M Col 22 (S)	CM 523-7 (IR)	M Ven 77 (R)
CBB	Angular leaf spots/leaf[a]	Sprayed[d]	1a*	0a	0a
		Control	7b	4b	4b
	Number of blighted leaves/plant[b]	Sprayed	1a	2a	0a
		Control	7b	8b	3b
SD	Number of elongated plants/plot[c]	Sprayed	4a	2a	0
		Control	14b	5b	0

[a] Average number of leaf spots/leaf on 15 leaves/plot (three leaves from each of five different plants). Plots contained 36 plants with three replications.

[b] Average number of blighted leaves/plant on five plants/plot. Plots contained 36 plants with three replications.

[c] Average number of elongated plants/plot. Plots contained 36 plants with three replications.

[d] Sprayed plants received six weekly foliar applications of a 1×10^9 cells/ml suspension of *Pseudomonas putida*. Control plants were sprayed with distilled water.

[e] S = susceptible; IR = intermediate resistant; R = resistant.

* Numbers followed by the same letter are not significantly different at a 0.05 level of the Duncan Multiple Range Test.

Table 9. Average yield of fresh roots and starch in relation to source of planting material and stake treatment of four clones grown at CIAT.

Source of cuttings and/or stake treatment	Yield (t/ha)[b]			
	M Col 22	CMC 40	CM 523-7	CM 342-70
Selected and treated[a]	24a*	13a	27a	23a
Selected, but not treated	24a	12a	15a	21ab
Not selected, but treated	18b	9ab	26a	21ab
Not selected and not treated	16b	6b	18b	17ab
Diseased cuttings and treated	13c	9ab	13c	17ab

[a] Visual selection for absence of disease or insect damage and for maturity, size and thickness. Cuttings were treated with a fungicidal/insecticidal mixture (Orthocide, Benlate and Malathion).

[b] Yield was recorded from four replicated plots of 30 plants each.

* Yields followed by the same letter(s) are not significantly different at the 0.05 level of the Duncan Multiple Range Test.

Table 10. Effect of stake selection on improving the relative yield of cassava clones at Media Luna, Carimagua, and CIAT.

Location		Average percentage of plants with higher (H) or lower (L) yield than the average for the year of selection		
		1983	1984	
			H	L
Media Luna	H[a]	70[b]	77[c]	23
(4)[d]	L	30	15	85
Carimagua	H	27	60	40
(3)[d]	L	73	36	64
CIAT	H	39	75	24
	L	61	15	85

[a] H = percentage of plants with higher yield than the plot average; L = percentage of plants with lower yield than the plot average.

[b] Data taken from approximately 100 plants. Cuttings taken from these plants were selected and treated with fungicide/insecticide (Bavistin-Orthocide-Malathion) before planting.

[c] Data taken from four replicated plots of 30 plants each.

[d] In parentheses the number of clones tested/location.

Table 11. Effect of stake selection on yield at Media Luna, Carimagua and CIAT.

Cultivar	Source of cuttings	Yield (t/ha)/location		
		Media Luna	Carimagua	CIAT
Secundina	H[a]	18a*		
	L	16a (9)[b]		
M Col 22	H	28a		
	L	17b (36)		
M Col 1684	H	28a		
	L	21b (26)		
Venezolana	H	21a		
	L	16b (25)		
CM 523-7	H		11a	
	L		8b (25)	
M Ecu	H		19a	
	L		15b (22)	
CMC 40	H		7a	18a
	L		5b (33.8)	15b (19)
M Ven 218	H			13a
	L			6b (52)

[a] H = percentage of plants with higher yield than the plot average; L = percentage plants with lower yield than the plot average.

[b] Data taken from four replicate plots of 30 plants each. In parentheses is the percentage of yield increase obtained by using stakes from high yielding plants.

* The figures in the same column are not significantly different at 0.05 level of the Duncan Multiple Range Test.

Table 12. Effect of cutting source and stake treatment on yield of two cassava clones with resistance (R) and intermediate resistance (IR) to pathological problems at Carimagua.

Cutting source		Fresh root yield (t/ha)	
		M Ecu 82 (R)	CMC 40 (IR)
Agronomia[a]	Treated[b]	19.2a*	7.4a
	Untreated	15.0b	2.6b
Reserva	Treated	10.0c	4.0b
	Untreated	8.0d	3.8b

[a] "Agronomia" is an area with better soil nutrition than the "Reserva" but both areas are on the Carimagua Station.

[b] Cuttings were treated with a fungicide/insecticide mixture (Bavistin-Orthocide-Malathion) before planting.

* Yields followed by the same letter are not significantly different different at the 0.05 level of the Duncan Multiple Range Test.

Table 13. Yield stability of the native clone Secundina and the clone CM 342-170 during four continuous cycles at Media Luna.

Clone	Cycle No.[a]	Fresh root[b] yield	Starch	Number of cuttings
Secundina	I	30.2a*	8.9a	5.7a
	II	25.9ab	7.7ab	6.1a
	III	20.7b	6.1b	3.5b
	IV	17.6c	5.2c	4.0b
	CK[c]	17.0c	5.3c	3.2b
CM 342-170	I	24.0a	6.4a	6a
	II	24.4a	6.4a	7a
	III	22.4a	5.9a	5a
	IV	23.1a	6.1a	5a

[a] Cycle I planting material was derived from thermotherapy-treated and meristem-cultured plants. Planting material for each successive cycle was obtained from the preceeding cycle. Cycles I through IV were harvested simultaneously.

[b] Data taken from four replicated plots of 36 plants each. Cuttings were selected and treated with a fungicide/insecticide mixture, (Bavistin-Orthocide-Malathion) before planting each cycle.

[c] CK refers to plots planted with planting material collected from traditional farms. The planting material was unselected and untreated, simulating the farmer's planting system.

* Yields followed by the same letter(s) are not significantly different at 0.05 of the Duncan Multiple Range Test.

TABLE 14. CASSAVA PESTS AND DISEASES IDENTIFIED AND EVALUATED IN FIVE DIFFERENT ECOSYSTEMS IN COLOMBIA DURING 1979 (I CYCLE), 1980 (II CYCLE), 1981 (III CYCLE), 1982 (IV CYCLE), AND 1983 (V CYCLE).

	LOCATION																									
	CARIBIA Año 19..					MEDIA LUNA Año 19..					CARIMAGUA Año 19..					CIAT Año 19..					POPAYAN Año 19..				
BMPFs	79	80	81	82	83	79	80	81	82	83	79	80	81	82	83	79	80	81	82	83	79	80	81	82	83
DISEASES																									
BACTERIAL BLIGHT	++ [A]	++	++	++		+	++	+	++	++	+++	+++	++	++	++	-	-	-	-	-	-	-	-	-	-
SUPERELONGATION	+	+	-	-		+	+++	+	+	-	+++	+++	+++	++	+++	-	-	-	-	-	-	-	-	-	-
CONCENTRIC RING-LEAF SPOT	-	-	-	-		-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	+++	++	++	+	++
ANTHRACNOSE	++	+++	+++	++		+	++	+	+	++	+++	+++	+++	++	++	+++	+	+	+	+	+++	++	++	+	++
BROWN LEAF SPOT	++	+++	+++	++		+++	+++	++	++	+++	++	+	++	+	+	+	++	++	++	++	-	-	++	-	+
BROWN LEAF BLIGHT	++	++	++	++		+	++	+	+	+	++	-	+	-	-	+	++	++	++	++	-	-	-	-	-
WHITE LEAF SPOT	++	+++	+++	+++		++	++	++	+	+++	-	-	+	-	+	-	-	-	-	+	-	+	+	+	+
BACTERIAL STEM ROT	+	+	+	+		+	+	+	+	+	+	+	+	-	+	++	++	+	-	+	-	-	-	-	+
CASSAVA ASH	-	+	+	-		-	++	+	-	-	-	-	-	-	-	+	+++	++	++	++	++	++	++	++	+
CASSAVA COMMON MOSAIC	+	++	++	+		+	++	+++	++	+++	-	-	-	-	-	++	++	+++	+	++	+++	+++	++	+	+
FROG SKIN DISEASE	-	+	+++	+++			+	-	-	-	-	-	-	-	-	-	++	+++	+++	+++	-	-	-	-	-
SMALLPOX	-	+	++	++		-	++	+	+++	++	-	-	-	-	+	-	+	++	++	++	-	-	-	-	+
ROOT ROTS	-	+	++	+++		-	+	+	+++	+++	-	+	+	+	+	-	++	+	++	++	-	-	-	+	+
CHOANEPHORA LEAF BLIGHT	-	-	+++	+++		-	-	++	++	+++	-	-	+++	+	+	-	-	-	-	-	-	-	-	-	-
DIPLODIA	-	-	-	+		-	-	-	+++	+++	-	-	-	+	++	-	-	-	+	++	-	-	-	-	-
ANTHOLYSIS									++	-				-	-				+	++	-	-	-	-	-
INSECTS																									
HORNWORM	+	+	+	-		+	+	+	+	-	+++	+	+	+	+	+	+	+	+	+	+	+	+	+	+
WHITEFLIES	++	+	+	++		++	+	++	+++	++	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
THRIPS	++	++	+	++		+	+	+	++	++	++	++	+	+	+	+++	+++	+++	+++	++	+	+	+	-	-
LACEBUGS	+	++	+	+		+	+	+	+	+	++	+++	++	++	++	++	++	+	+	+	+	+	-	-	-
SHOOT FLIES	+	+	++	+		+	-	-	-	-	+	+	+	+	+	++	+	+	+	+	-	-	-	-	++
FRUITFLIES	+	+	+	+		-	-	-	+	+	+	-	+	+	+	+	+	+	+	+	+	-	-	-	+++
LEAF BEATLES	-	-	-	-		-	-	-	-		-	-	-	-		++	++	++	++	++	-	-	-	-	+
GALLMIDGES	+	+	+	+		+	+	+	+	+	++	+++	++	++	++	+	-	-	-	+	-	-	-	-	-
TERMITES	+	+	-	-		++	++	+	++	++	+	+	+	+	+	-	-	-	-	-	-	-	-	-	-
STEMBORERS	-	-	-	-		-	-	-	-	-	++	++	++	++	+++	-	-	-	-	-	-	-	-	-	-
LEAF CUTTER ANTS	-	-	+	+		-	-	+	+	+	++	-	++	++	++	-	-	-	-	-	-	-	-	-	-
SCALES	-	-	-	-		+	-	-	+	+	+	+	+	+	+	-	-	-	-	-	+++	+++	++	++	+++
MEALYBUGS	-	-	-	-		-	-	-	-	-	-	-		-	+++	-	-	+	++	++	-	-	-	-	-
MITES																									
Mononychellus sp.	+	+	+	+		++	++	+	+++	++	+	+	+	+	+	++	+++	++	++	+++	+	+	+	+	+
Tetranychus sp.	+	+	-	-		+	+	-	++	++	+	+	-	+	+	+	++	++	++	+++	-	-	-	-	-
Oligonychus sp.	+	++	++	++		+	+	++	+++	+++	++	-	+	++	++	++	+++	+++	+++	+++	++	+++	+++	+++	+++

[A] +++ = SEVERE DAMAGE; ++ = MODERATE DAMAGE; + = LIGHT DAMAGE; - = NOT OBSERVED.

TABLE 15. MAXIMUM (MX), MINIMUM (MN), AVERAGE ($\bar{X}$) VALUES FOR YIELD (T/HA), STARCH (T/HA), STAKE PRODUCTION (NUMBER OF CUTTINGS/PLANT), DETERIORATION (%), HARVEST INDEX AND HCN CONTENT OBTAINED FROM ALL 31 CULTIVARS IN CIAT, MEDIA LUNA, CARIMAGUA, CARIBIA AND POPAYAN ECOSYSTEMS (FIRST, SECOND, THIRD, FOURTH AND FIFTH CYCLES).

		YIELD (T/HA)			STARCH (T/HA)			STAKE PROD./ PLANT			HARVEST INDEX[1]			CYANIDE CONTENT[2]			DETERIORATION (%)[3]		
ECOSYSTEM	CYCLE	MX	MN	$\bar{X}$	MX	MN	$\bar{X}$	MX	MN	$\bar{X}$	MX	MN	$\bar{X}$	MX	MN	$\bar{X}$	MX	MN	$\bar{X}$
CIAT	I	74.1	0.0	24.4	24.7	0.00	7.7	18.0	0.6	10.0	0.65	0.00	0.41	5.0	1.0	2.6	90.0	1.6	26.5
	II	55.4	1.6	20.8	17.1	0.34	6.9	34.8	7.6	17.5	0.71	0.05	0.46	5.0	2.0	3.2	49.5	1.3	14.2
	III	36.4	1.0	19.8	11.4	0.00	6.0	23.3	7.9	14.0	0.74	0.11	0.51	5.0	2.0	3.3	67.4	1.2	16.3
	IV	42.7	0.4	20.2	12.8	0.86	6.6	29.8	5.9	15.2	0.69	0.02	0.45	-	-	-	22.9	0.0	5.4
	V	38.8	0.6	11.5	12.1	0.22	3.5	16.6	4.8	9.5	0.77	0.04	0.47	-	-	-	-	-	-
MEDIA LUNA	I	19.0	0.4	9.5	3.7	0.06	1.9	11.0	1.0	5.0	0.65	0.13	0.44	5.0	1.0	2.9	7.6	0.0	1.4
	II	70.1	0.0	27.0	15.4	0.00	7.1	16.5	0.0	7.1	0.80	0.00	0.56	5.0	2.3	3.7	16.0	0.3	4.0
	III	37.8	0.0	17.0	9.8	0.00	4.1	22.4	0.0	10.1	0.79	0.27	0.59	4.7	2.3	3.2	10.8	0.0	2.5
	IV	33.1	0.0	15.4	8.6	0.00	3.5	22.5	0.0	10.7	0.71	0.11	0.55	-	-	-	3.5	0.0	0.8
	V	24.8	0.0	10.9	6.1	0.00	2.6	18.1	0.0	10.3	0.72	0.23	0.53	-	-	-	-	-	-
CARIMAGUA	I	10.7	0.5	2.5	2.8	0.01	0.7	5.0	0.0	1.0	0.66	0.02	0.39	5.0	2.0	3.3	26.9	0.0	1.4
	II	11.6	0.0	1.9	2.9	0.00	0.6	10.5	0.0	0.7	0.61	0.00	0.15	4.3	2.7	3.3	0.1	0.0	0.0
	III	11.6	0.0	1.4	2.8	0.00	0.3	6.6	0.0	0.9	0.59	0.28	0.47	5.0	2.3	3.4	3.6	0.0	1.2
	IV	10.1	0.0	1.2	2.3	0.00	0.3	6.8	0.0	1.1	0.73	0.36	0.49	-	-	-	1.8	0.0	0.6
	V	10.0	0.0	1.1	3.0	0.00	0.2	9.9	0.0	1.0	0.47	0.24	0.36	-	-	-	-	-	-
CARIBIA	I	55.9	2.4	23.2	16.3	0.33	6.4	16.0	2.0	8.2	0.61	0.12	0.40	5.0	1.0	3.0	28.1	0.0	3.6
	II	86.0	5.6	30.6	24.0	1.30	8.0	20.6	1.6	8.7	0.90	0.27	0.66	5.0	2.6	3.9	21.4	0.5	5.1
	III	46.6	0.6	22.5	12.0	0.10	5.7	13.6	1.2	11.7	0.74	0.07	0.55	5.0	2.0	3.3	10.7	0.0	1.8
	IV	32.4	0.3	17.8	8.5	0.07	4.4	26.3	0.0	16.1	0.79	0.08	0.59	-	-	-	18.8	0.1	5.9
	V	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
POPAYAN	I	21.3	0.2	4.9	6.9	0.04	1.6	8.0	0.0	2.3	0.66	0.10	0.36	5.0	1.0	2.7	82.6	2.3	27.1
	II	26.4	0.0	5.9	8.8	0.00	2.0	16.9	0.0	5.3	0.32	0.00	0.47	5.0	1.3	3.0	71.8	7.0	42.0
	III	16.9	0.0	3.2	5.3	0.17	1.2	12.2	0.6	3.5	0.63	0.12	0.42	5.0	2.0	3.6	91.1	8.6	39.2
	IV	17.6	0.0	4.6	5.5	0.00	1.4	16.9	0.0	3.7	0.79	0.09	0.55	-	-	-	-	-	-
	V	18.2	0.0	2.3	4.9	0.00	0.7	11.2	0.0	1.5	0.75	0.00	0.46	-	-	-	-	-	-

[1]HARVEST INDEX (ROOT FRESH WEIGHT/ROOT FRESH WEIGHT + FOLIAGE WEIGHT X 100)

[2]PICRATE PAPER METHOD: 5 = HIGH AND 0 = LOW HCN CONTENT

[3]100% TOTAL DETERIORATION: 0% = ZERO DETERIORATION 3 DAYS AFTER HARVEST

[4]MX = MAXIMUM; MN = MINIMUM; $\bar{X}$ = AVERAGE

[5]I = (1979-80); II = (1980-81); III (1981-82); IV = (1982-83); V = (1983-84).

TABLE 16. RELATIONSHIPS BETWEEN ECOSYSTEMS AS REGARDS YIELD, STARCH CONTENT (%), NUMBER OF STAKES, DETERIORATION (%), HCN CONTENT, HARVEST INDEX AND GENERAL EVALUATION ARE SHOWN BY THE CORRELATION COEFFICIENT (R) FROM THE 31 CULTIVARS GROWN IN EACH ECOSYSTEM (FIRST, SECOND, THIRD, FOURTH AND FIFTH CYCLES).

ECOSYSTEMS	CYCLE	YIELD (TONS/HA)	STARCH CONTENT (%)	NUMBER OF STAKES	DETERIORATION (%)	HCN CONTENT	HARVEST INDEX
CIAT-POPAYAN	I	-0.116[2]	0.019	0.026	0.129	0.354	-0.052
	II	0.035	-0.013	0.178	-0.264	0.565***	0.189
	III	-0.194	-0.305	0.036	0.484	0.368	0.283
	IV	0.060	-0.066	-0.066	-	-	0.562**
	V	-0.126	-0.140	-0.158	-	-	0.345
CARIMAGUA-POPAYAN	I	-0.152	-0.304	-0.038	-0.215	0.488*	-0.077
	II	-0.041	0.078	0.105	0.067	0.233	0.201
	III	-0.154	-0.157	-0.003	0.586	0.616	-0.468
	IV	-0.054	0.078	-0.054	-	-	-0.021
	V	-0.122	-0.138	-0.085	-	-	0.524
MEDIA LUNA-POPAYAN	I	-0.92	0.163	-0.084	0.130	0.451*	0.301
	II	-0.091	-0.196	0.015	0.187	0.409	0.234
	III	-0.311	-0.353*	-0.286	-0.249	0.552**	0.435*
	IV	-0.191	-0.237	0.054	-	-	0.312
	V	-0.244	-0.269	-0.158	-	-	0.152
CARIBIA-POPAYAN	I	-0.581**	-0.062	-0.325	-0.022	0.318	-0.342
	II	-0.435**	-0.421*	-0.549***	0.519**	0.327	0.223
	III	0.443*	-0.430**	-0.526**	-0.247	0.466*	0.048
	IV	-0.200	-0.206	-0.412*	-	-	0.381
	V	-	-	-	-	-	-
CIAT-CARIMAGUA	I	0.273	0.415*	-0.101	0.359	0.567**	0.603***
	II	-0.190	-0.241	-0.160	-0.049	0.408*	0.219
	III	-0.135	-0.873**	0.037	-0.296	0.741*	-0.123
	IV	0.145	-0.013	-0.014	-0.522	-	-0.213
	V	-0.277	-0.291	-0.318	-	-	0.289
CIAT-MEDIA LUNA	I	0.540**	0.294	-0.299	0.209	0.224	0.801***
	II	0.563***	0.552***	0.403*	0.475**	0.539***	0.806***
	III	0.613***	0.610***	0.474**	0.584**	0.427*	0.773***
	IV	0.676***	0.626***	0.310	0.602**	-	0.841***
	V	0.277	0.211	0.285	-	-	0.674***
CIAT-CARIBIA	I	0.760***	0.390	0.430*	0.115	0.374*	0.649***
	II	0.265	0.266	-0.040	0.116	0.356*	0.801***
	III	0.398*	0.490**	0.077	0.583**	0.644***	0.614***
	IV	0.545***	0.493**	0.136	0.369	-	0.616***
	V	-	-	-	-	-	-
CARIMAGUA-MEDIA LUNA	I	0.664***	0.591**	0.446**	0.552**	0.389*	0.536**
	II	0.366*	0.309	0.447*	-0.017	0.305	0.255
	III	0.283	0.151	0.430*	0.559	0.837**	-0.349
	IV	0.342*	0.263	0.535**	0.039	-	0.202
	V	0.449*	0.280	0.352	-	-	0.342
CARIMAGUA-CARIBIA	I	0.483**	0.472*	-0.218	0.461*	0.214	0.522*
	II	0.309	0.224	0.333	-0.239	0.248	0.171
	III	0.466**	0.377	0.404*	-0.300	0.866**	0.252
	IV	0.188	0.212	0.463**	0.835**	-	0.033
	V	-	-	-	-	-	-
MEDIA LUNA-CARIBIA	I	0.661**	0.535**	0.235	0.416*	0.567**	0.622***
	II	0.573***	0.593***	0.301	0.346	0.512**	0.739***
	III	0.630***	0.621***	0.460**	0.568**	0.646***	0.699***
	IV	0.574***	0.617***	0.401*	0.315	-	0.681***
	V	-	-	-	-	-	-

* = SIGNIFICANT AT 5% LEVEL; ** = SIGNIFICANT AT 1% LEVEL; *** = SIGNIFICANT AT 0.1% LEVEL.

1 =CYCLE I (1979-1980); II = CYCLE II (1980-1981); III = CYCLE III (1981-1982); IV = CYCLE IV (1982-1983); V = CYCLE V (1983-1984).

2 = RESULTS OF YIELDS, STARCH CONTENT AND NUMBER OF STAKES ARE FOR THE 31 CLONES INITIALLY PLANTED; THE OTHER PARAMETERS ARE ONLY FOR CLONES SURVIVING AT EACH ECOSYSTEM.

Table 17. Maximum disease severity at 11 sites of regional trials seven months after planting.

Disease	Disease severity/site										
	CIAT	Media Luna	Albania	Carranzo	S/Larga	Sta.Cruz	Carimagua	Granada	Gaitan	Popayan	Quilcace
Cassava bacterial blight	0	3	3	2	2	2	5	0	0	0	0
Superelongation	1[a]	0	0	0	0	3	5	4	4	0	0
Diplodia root rot	5	5	0	0	0	0	2	0	0	2	2
Anthracnose	4	3	4	3	3	3	5	0	0	5	3
White leaf spot	2	2	3	4	4	4	2	3	3	4	2
Brown leaf spot	3	4	3	4	4	3	4	3	0	0	2
Blight leaf spot	4	3	2	3	2	3	4	3	4	0	4
Viral mosaics	3	5	0	0	3	3	0	0	0	0	0
Cassava ash disease	4	0	0	0	0	0	0	0	0	3	3
Concentric-ring leaf spot	0	0	0	0	0	0	0	2	0	5	0
Choanephora leaf blight	0	2	4	3	3	0	3	0	0	0	0
Bacterial stem rot	2	0	4	4	0	0	2	0	0	3	0
The frog skin disease	0	0	0	0	0	0	0	0	0	0	5

[a] Disease severity: 1 = the lowest disease symptoms; 5 = the most severe symptoms.

VIROLOGY

Cassava Virology research in 1984 had three principle objectives: (1) to isolate and identify the etiological agents for cassava viral diseases; (2) to develop sensitive and rapid detection methods; and (3) to study virus spread and transmission. Advances were made in some of the above research areas for Caribbean mosaic, latent and frog skin diseases and an isolate of the cassava common mosaic virus.

Caribbean Mosaic Disease

The cassava pathology program conducted yield stability and planting material selection trials with M Col 2063 (Secundina) a local variety on the North Coast of Colombia during 1983 and 1984 (Cassava Annual Reports, 1983 and 1984). Selected plants from these trials were indexed for the Caribbean mosaic disease (CMD) (Table 1). The incidence of CMD was high irrespective of the source of planting material. The re-infection rate of newly introduced "clean" material was high in both 1983 and 1984, suggesting the involvement of an insect vector. A high population of whiteflies was observed on CMD-infected plants in November, 1984 therefore CMD-whitefly transmission studies are in progress. The absence of CMD field symptoms at harvest in June 1983 confirmed previous observations on the suppression of symptom development at high ambient temperatures (Cassava Annual Report 1983).

Latent Disease

A virus was mechanically-transmitted from cassava plants infected with a symptomless latent disease (Cassava Annual Report, 1983) to *Chenopodium quinoa*. Large, chlorotic local lesions were produced on *C. quinoa* 8-10 days after inoculation (Figure 1). Very long, flexuous rod-shaped virus particles were observed with the electron microscope in a partially-purified fraction from infected *C. quinoa* plants (Figure 2). The virus retained infectivity following: homogenization; chloroform treatment; polyethylene glycol precipitation; sucrose cushion pelleting, and sucrose gradient centrifugation. The role of the isolated virus in the etiology of the latent disease requires further investigation.

Last year a symptomless latent infection was detected in 40% of the 150 clones graft-indexed onto the symptom-producing Secundina clone (Cassava Annual Report 1983). In 1984 an additional 59 clones, originating from various regions of Central and South America were graft-indexed. A symptomless latent disease agent was detected in at least one clone from each of the regions tested and in a total of seven of the 59 clones indexed. These results indicate the likely widespread distribution of this disease in Latin American cassava.

Frog Skin Disease

The third year of a trial to measure the stability of selected clones to frog skin disease (FSD) was completed in 1984. Two native and two introduced cassava clones, originating from thermotherapy-treated and meristem-cultured plants, were planted in a FSD endemic area near Quilcace, Colombia and evaluated for 2 or 3 successive growth cycles. The second and third cycle fresh root yield of the native and introduced clones was consistently less than the yield of first cycle plants (Figure 3). The incidence of FSD was generally higher in the

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later cycles with the exception of the clone CMC 40 which was not affected by the FSD. The rate of re-infection of "clean" Quilcace Peciolo Rojo (QPR) and CM 321-188 material by FSD was relatively slow in comparison to the re-infection rate of Valluna and the control clone Secundina. The performance of the native clone QPR was the most stable in respect to yield and checking the build-up of FSD. The source of the frog skin agent involved in re-infection is not known, however, preliminary results from a planting date trial suggest that most of the re-infection is due to a mobile vector transmitting the FSD agent to the crop from an outside source. The incidence of FSD in plots of Secundina was nearly 100% within 100 days of planting in April, May, June, and July. The several species of whiteflies consistently observed on cassava seedlings before the appearance of symptoms were trapped, identified and will be used in controlled transmission experiments.

Cassava Common Mosaic Virus

A flexous, rod-shaped virus isolated from CMD-infected cassava (Cassava Annual Report, 1982) was identified as an isolate of cassava common mosaic virus (CCMV), based on host range, serological reaction and the size and shape of the virus particle. The experimental host range of the Caribbean mosaic disease isolate was quite similar but not identical to the host range of CCMV (Table 2).

Using the immunosorbent electron microscope (ISEM) technique the Caribbean mosaic disease isolate was determined to be serologically-related to CCMV, *Narcissus* mosaic, and potato virus X virus, all members of the plant potexvirus group. The ISEM technique combines the specificity and sensitivity of serology with electron microscopy through the use of electron microscope grids pre-coated with virus specific antibodies to selectively trap virus particles onto the grid surface. The number of virus particles trapped on homologous antibody-coated grids is significantly increased (Figure 4).

ISEM has many applications in cassava virus research including rapid virus identification and detection, determination of serological relationships between viruses (Table 3), and increasing the number of virus particles for observation and measurement (Figure 5).

The double-antibody sandwich form of the enzyme-linked immunosorbent assay (ELISA) is also now available for the serological detection of CCMV in cassava. The ELISA test is a sensitive, rapid, and cost-efficient method for a large-scale cassava virus indexing program. The test is conducted in small wells in a plastic microtiter plate and provides results within 36 hours (Figure 6). Using the ELISA procedure it is possible to virus index several hundred samples in a single day by processing very small leaf tissue pieces from plants or plantlets. The ELISA test will be used to index for other Latin American cassava viruses as antisera become available.

Table 1. The percentage of Secundina plants affected by the Caribbean mosaic disease (CMD) in yield stability trials at Media Luna in 1983 and 1984.

Planting material	% plants with CMD	
	1983-84[a]	1984-85[b]
From thermotherapy-treated, meristem-cultured plants		
Cycle I	58	80
Cycle II	75	100
Cycle III	100	100
From plants from farmer's fields selected free of pest and disease damage	100	100
No selection criteria used	100	100

[a] Plants were indexed at harvest in June 1984 by sprouting stakes in the glasshouse and observing symptom development.

[b] Plants were indexed in November 1984 by observing symptoms on five-month old plants in the field.

Table 2. The experimental host ranges of cassava common mosaic virus and an isolate from Caribbean mosaic diseased-cassava.

Cassava common mosaic virus	CMD-isolate
Chenopodium amaranticolor	*C. quinoa*
Chenopodium murale	*C. murale*
Chenopodium quinoa	*C. quinoa*
Nicotiana benthamiana	*Euphorbia prunifolia*
Ricinus communis	

Table 3. Serological relationship between a virus isolated from Caribbean mosaic diseased-(CMD)-cassava and members of the plant potexvirus group, using ISEM.

Antisera	Relative number of CCMV[a] particles trapped[b]
CMD-Isolate	916
Cassava common mosaic	713
Potato virus X	80
Narcissus mosaic	21
Cactus virus X	14
Hydrangea ringspot	12
Nerine virus X	9
Tulip virus X	8
Normal Rabbit Serum	9

[a] Cassava common mosaic virus (CCMV).

[b] Electron microscope grids were pre-coated with each of the antisera listed and then used to trap CCMV particles. The total number of particles counted in 10 viewing areas at 50,000 X is listed.

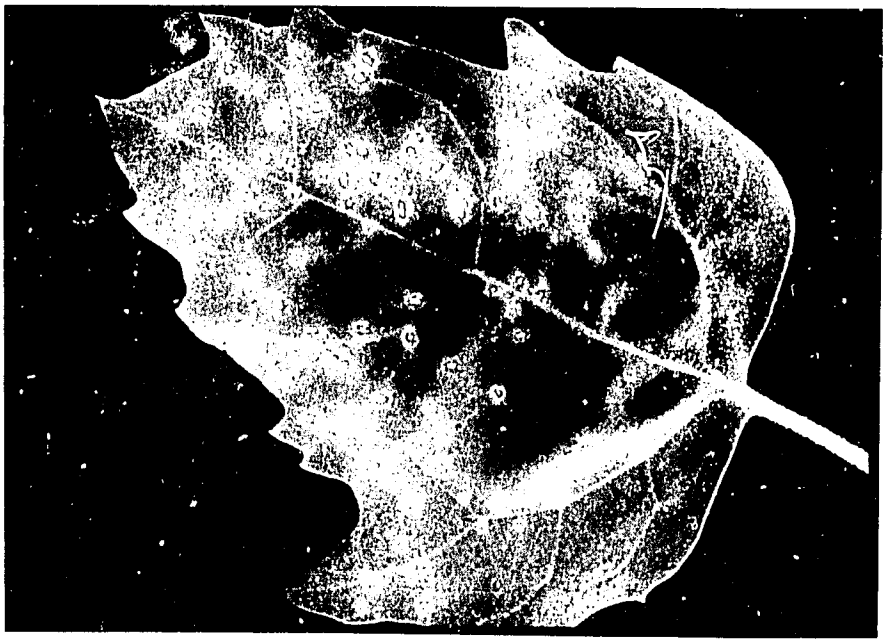

Figure 1. Chlorotic local lesions produced on Chenopodium quinoa by a symptomless latent disease of cassava.

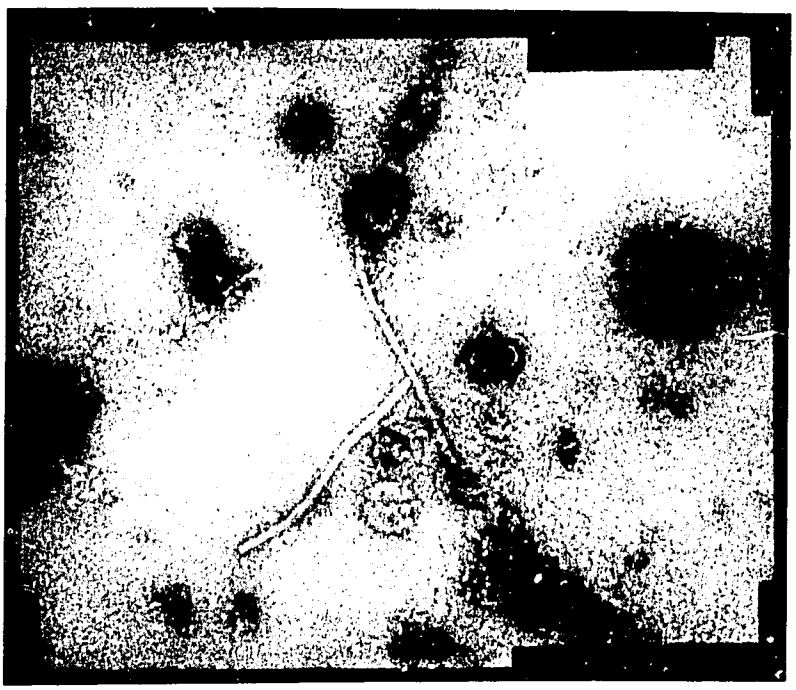

Figure 2. Very long flexuous rods observed in a partially purified virus preparation from a latent disease-infected Chenopodium quinoa plant.

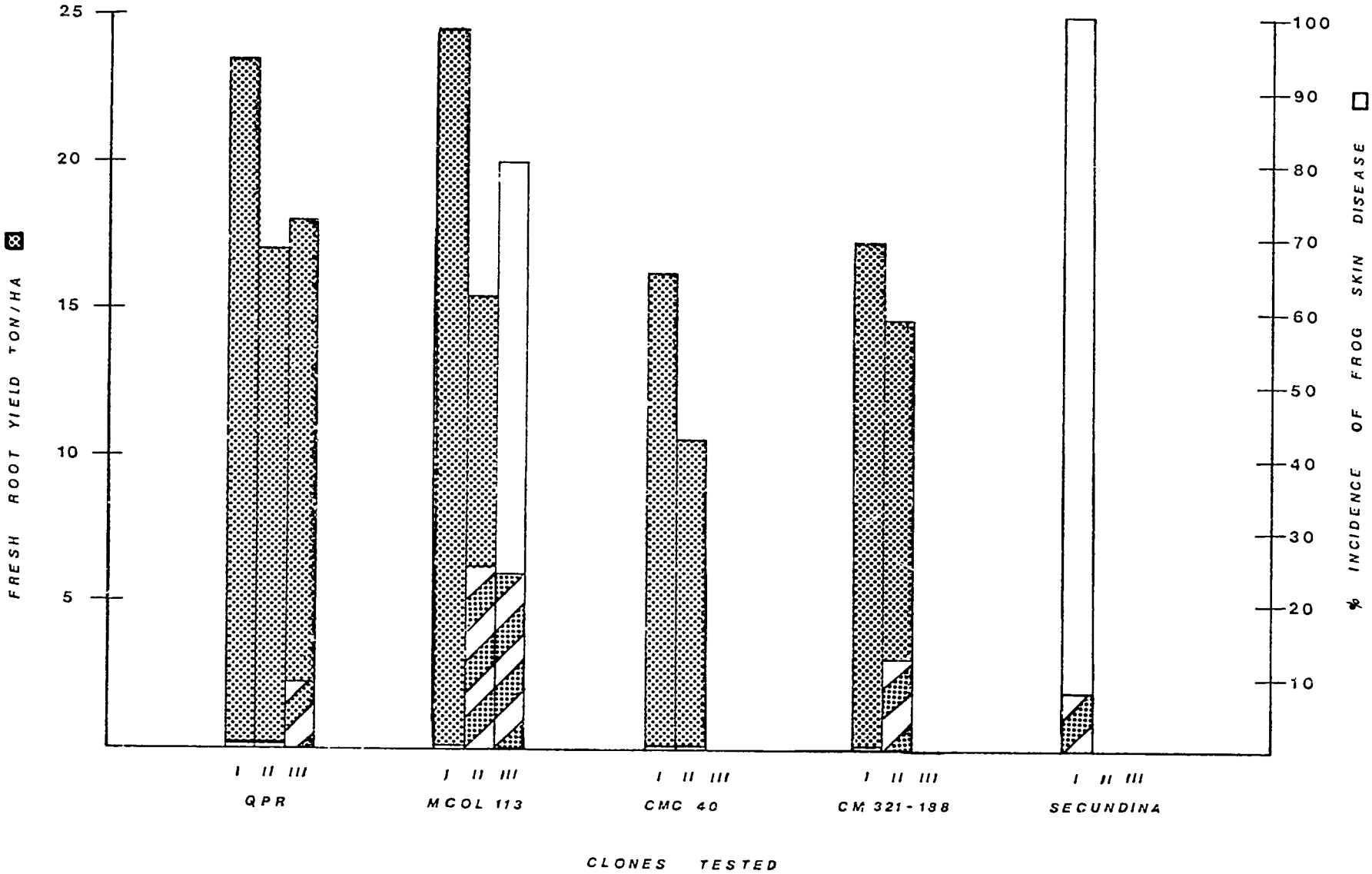

Figure 3. Fresh root yield and percent Frog Skin infection of two native and two introduced clones planted in a Frog Skin endemic area near Quilcacé.

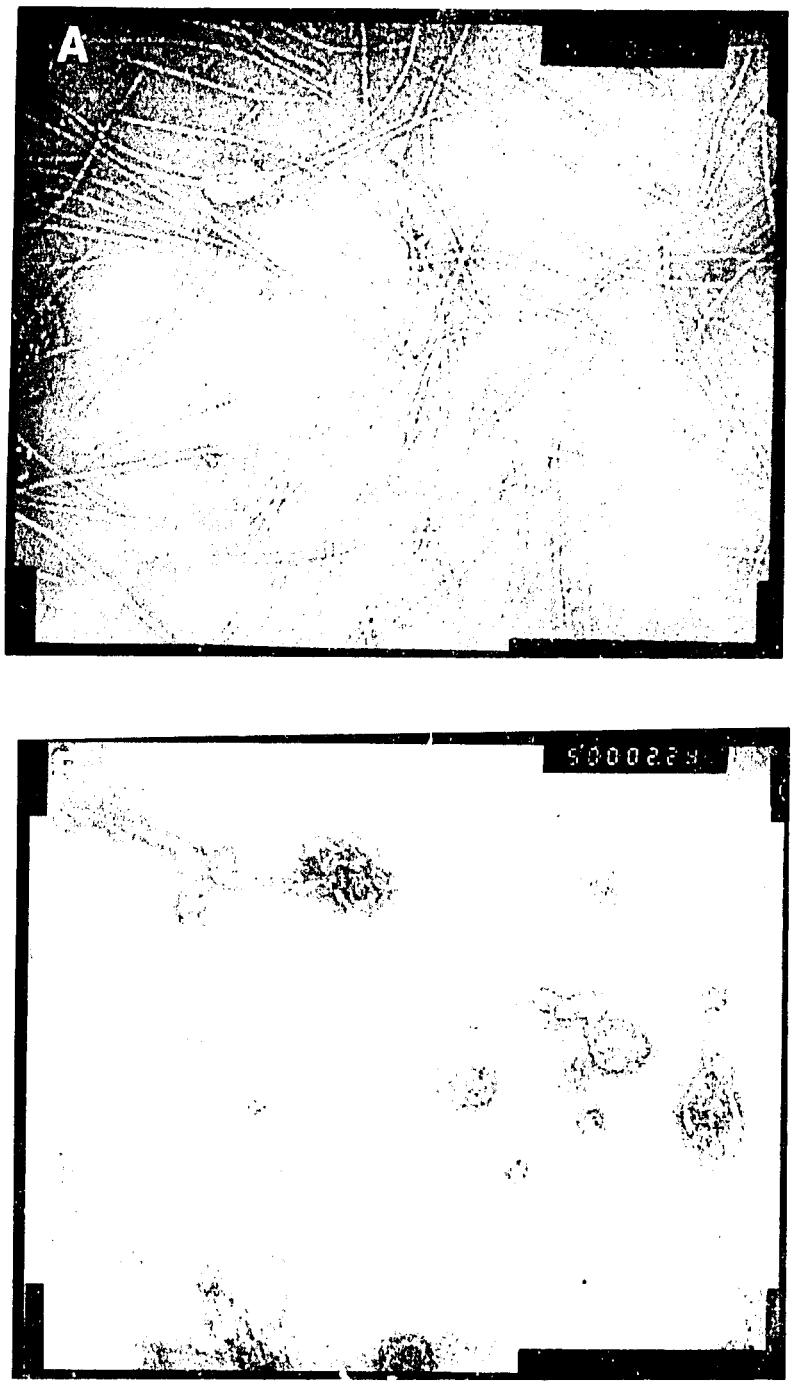

Figure 4. A comparison of the number of cassava common mosaic virus particles trapped on the surface of grids coated with: (a) homologous virus antiserum; and (b) normal serum.

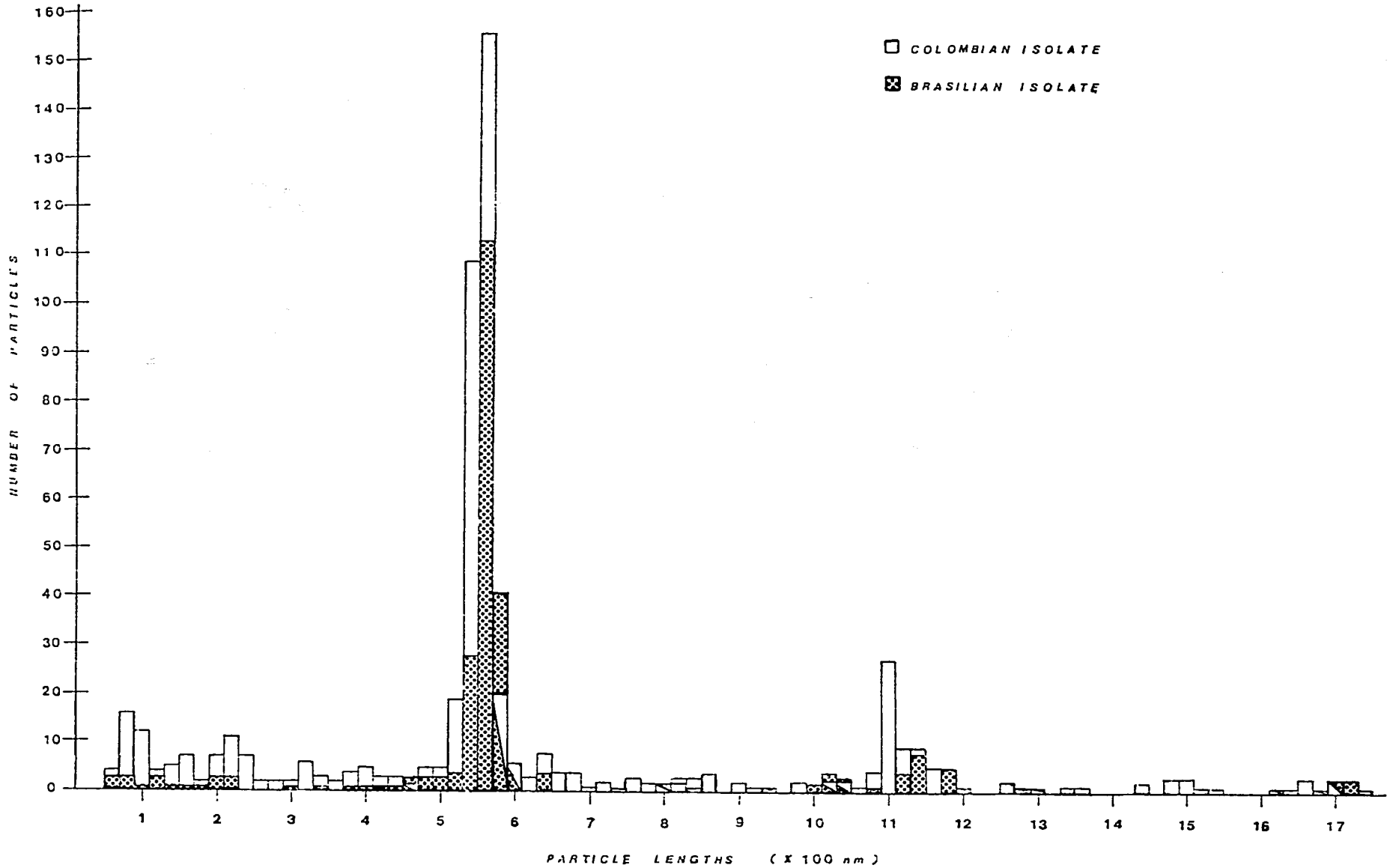

Figure 5. The length distribution of virus particles of cassava common mosaic virus and the CMD isolate. Virus particles were trapped on this grid surface with homologous antiserum.

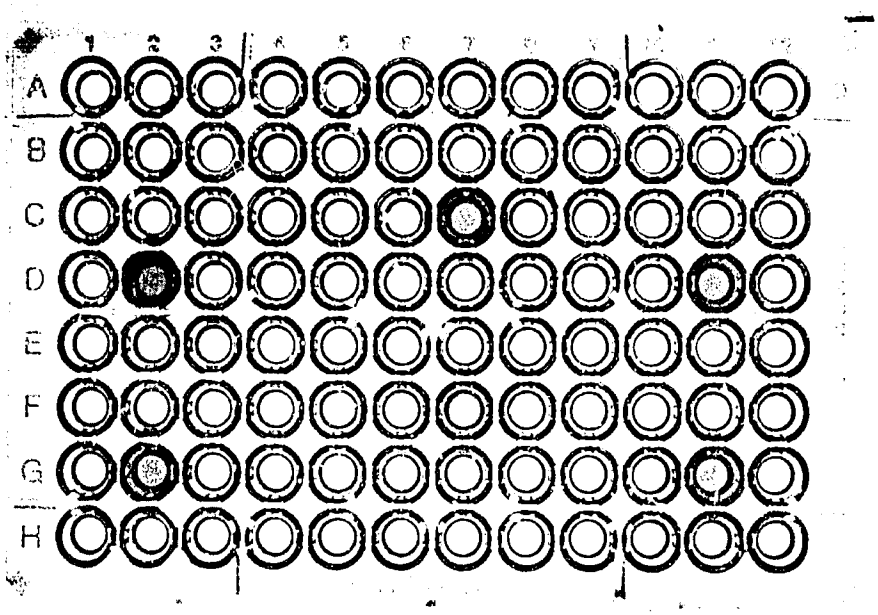

Figure 6. An ELISA plate with several typical virus positive reactions (observe the color development).

ENTOMOLOGY

In recent years, two cassava pests have caused severe damage to the cassava crop in Africa and the Americas, mites and mealybugs. Mites have been a traditional pest of cassava in the Americas and in the last 10 years have caused severe crop losses in Africa. Mealybugs have only recently become important pests and two species, Phenacoccus manihoti in Africa, and P. herreni in the Americas, are causing severe crop losses. Much of the entomology research done during 1984 concentrated on these pests and will continue to do so for the next several years.

In addition, studies on Cyrtomenus bergi, hornworms, stemborers, whiteflies and termites continued.

Cyrtomenus bergi

This soil born insect can drastically reduce the commercial value of cassava roots. Insect feeding combined with soil pathogens results in the presence of brown to black spots on the white fleshy roots resulting in a loss of market value.

Population fluctuations were measured at Santander de Quilichao from December 1983 to September 1984 on two varieties, CMC 40 (low cyanide (HCN) content) and M Mex 59 (intermediate HCN content). Adults and immature stages of C. bergi attacked roots from the second month of crop growth (Figure 1). Populations were more than three times greater in the variety CMC 40 than in M Mex 59. Populations of C. bergi peaked during the third month of crop growth, then fell and remained low throughout the rest of the plant growth cycle, although previous results had showed a tendency toward increasing populations with plant development for CMC 40 and a slight reduction in M Mex 59. The possibility of a relationship between soil moisture and C. bergi populations is suggested and should be investigated.

Preference studies were carried out at Santander de Quilichao employing two planting designs and three varieties, CMC 40 (low HCN content), M Mex 59 (intermediate HCN content) and M Col 1684 (high HCN content). One design consisted of planting all three varieties in a completely randomized block so that there was no single grouping of any one variety. In a second design, the same three varieties were planted in randomized blocks of 36 plants each with four replications.

Results from the first design show a high preference for the sweet or low HCN variety CMC 40 even though plants were randomly planted. Sixty one percent of CMC 40 roots and 36% of M Mex 59, an intermediate HCN variety were damaged, while only 12.5% of M Col 1684 roots, the high HCN variety, were damaged. These results indicate that even when plantings are completely mixed the insect selects the low HCN variety and that there is a high preference for the sweet variety.

Results of the second design show even more dramatically C. bergi's preference for feeding on sweet varieties. Eighty-five percent of the CMC 40 roots were damaged while only 4.2% of M Col 1684 roots were damaged. The intermediate HCN variety M Mex 59 had 20% root damage.

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These results also indicate that although the mixing of high and low HCN varieties may somewhat reduce the damage to the low HCN variety, the reduction is not large enough to be utilized as an effective control measure. The use of a high HCN variety as a border around fields of sweet varieties would probably not be an effective control practice.

Cultural control measures

Numerous plant species possess insecticidal qualities. i.e. they can detrimentally affect the development of insects or may act as a repellent to certain insect species or affect insect development or presence in various other ways. Crotalaria sp. (Sunne hemp) is known to have insecticidal qualities.

Preliminary laboratory studies tested the ability of C. bergi to feed on the roots of several crops including cassava, corn, sorghum and Crotalaria sp. Results showed a no-preference for feeding on Crotalaria and a preference for the other species. Therefore several experiments were designed to study the effectiveness of intercropping and rotation of Crotalaria and cassava, and to compare this to chemical control and varietal preference. These studies are being carried out in collaboration with Department of Entomology of the Universidad de Caldas.

The pesticide treatment, Dimethoate 2 cc/lt. water, applied every 15 days, did not effectively control C. bergi on the low HCN variety. Chiroza Callinaza (Table 1), which had 30.0 and 61.2% root attack for the treated and non-treated plots respectively while both the treated and non-treated plots of M Col 1684 (high HCN) were completely free of C. bergi attack. This indicates that pesticide control of C. bergi would be a costly and not completely effective means of control where there are high populations of the pest.

Meanwhile, cassava intercropped with Crotalaria had only 3.7% root damage as compared to 61.2% damage in monoculture (Table 1). Intercropping with Crotalaria is considerably more effective than the pesticide treatment. However, it reduced yield by about 22%. When the two systems are compared, the loss in commercial yield due to C. bergi damage was 61%, considerably more than the reduction caused by intercropping. Several intercropping designs will be tested to see if cassava yields can be increased while controlling C. bergi.

Mites

The cassava mite complex constitutes more than 46 species attacking cassava in nearly all regions where cassava is cultivated. Mites are dry season pests and can cause considerable yield losses during prolonged dry periods. Control of mites through pesticide applications is costly and often ineffective. Therefore, research emphasis has been given to the use of resistant varieties and natural enemies to control the pest. The research at CIAT in the Americas is closely linked with research efforts in Africa where mites, especially those of the genus Mononychellus, are causing severe crop losses.

Varietal resistance

Several cassava lines resistant to the Mononychellus mite have been identified. Five hybrids were compared to one of the parents, M Col 22. All of the hybrids, with the exception of one, C G 5-99, easily outyielded M Col 22 (Table 2). General mite populations were low throughout the year causing little damage to the crop.

Biological control

There is a large complex of insect and mite predators of cassava mites. In the past this complex has not been extensively studied, however the Phytoseiid mite complex has been given special emphasis as these predators are now considered to be more important than insect predators to maintain cassava mites at low densities, especially those of the Mononychellus complex.

A systematic exploration of the cassava fields in the Department of Valle, Colombia was continued during 1984; in addition some explorations were carried out on the Atlantic Coast of Colombia near Valledupar, Cesar. Preliminary identifications were done at CIAT and taxonomic verifications were done at the University of California, Riverside.

Explorations done in the Departament of Valle resulted in the identification of 12 species of Phytoseiid mites feeding on the cassava mite complex (Table 3). These were represented by five genera: Typhlodromalus, Amblyseius, Galendromus, Neoseiulus, and Typhlodromips. Of the species represented in Table 3, only T. limonicus, G. annectens, N. anonymus, and T. aripo, were previously registered as feeding on cassava mites in Colombia. The two species most frequently identified on cassava mites in Valle were T. limonicus and Neoseiulus anonymus. T. limonicus was found at the most sites while N. anonymus was the most abundant species found.

The biology and behavior of these latter two species were studied under laboratory conditions for which a technique was developed to study individual Phytoseiid mites predating on cassava mites feeding on cassava leaves. Small plastic cylinders 2 cm in diameter and 1 cm high were constructed. A humid disc of filter paper and a cassava leaf disc (variety CMC 40) were placed on the bottom of each cylinder with the lower surface of the leaf disc facing up. Each cage was sealed with transparent plastic adhesive which permitted observation.

The life cycles of T. limonicus and N. anonymus were studied by feeding them two species of phytophagous mites, Tetranychus urticae and Mononychellus progresivus. Results show that the life cycle of the immature stages of N. anonymus was the same when feeding on either of the two phytophagous species. The egg to deutonymph stage was 112.8 hours (4.7 day) and 112.34 hours (4.6 days) when feeding on T. urticae and M, progresivus, respectively (Tables 4 and 5). The adult stages of N. anonymus were considerably longer (about double) when feeding on T, urticae when compared to M. progresivus.

There was considerable difference in oviposition of N. anonymus when feeding on the two species. When offered T. urticae as food the

number of eggs oviposited per female per day was 2.47 (N = 43); when offered M. progresivus it was 0.55 (N = 51).

The life cycle of T. limonicus differed when fed on the two Phytophagus species. First of all, the species did not successfully feed on T. urticae due to the production of webs by the latter. These observations confirm findings of other workers. In addition, this explains why the entomology section has always observed, under field conditions, an association of T. limonicus and Mononychellus mite populations, which do not produce heavy webbing. Life cycle studies of T. limonicus were completed using only M. progresivus as food. Results show that the egg to deutonymph stage is 163.2 hours (6.8 days), about 50% longer than N. anonymus (Table 6). Adult duration was also longer.

Future research will involve studies of these species under different temperature regimes.

Field ecology studies

Population fluctuation of Phytophagus and Phytoseiid mites were studied on several genotypes in the field. In general, Phytophagus mite populations (principally M. progresivus) increased during periods of low rainfall and decreased during rainy periods (Figure 2).

Phytoseiid mite populations increased as Phytophagus mite populations increased and decreased when they did. Mite populations were generally low throughout the year.

Mealybugs

Mealybugs are a pest that only recently has become important in cassava as it is only in the last 10 years that they have been reported as damaging to the crop. There are two major species: Phenacoccus manihoti and P. herreni. Both species are present in the Americas, but only P, manihoti has been reported in Africa where it causes severe crop losses. P. herreni is causing severe damage in certain areas of the Americas, especially in the northeast of Brazil. P. manihoti appears to be restricted to localized areas of Brazil, Paraguay and Bolivia and is not reported as causing crop losses in the Americas.

Yield losses

Yield losses for P. manihoti have been quantified in Africa (46% reduction in root yield), but not in the Americas so that mealybug losses were estimated in two varieties (M Col 22 and CMC 40) using artificial infestation and Sistemin sprays for control. Typical damage symptoms of the cabbage-like effect on the growing points and leaf and stem distortion were more pronounced for M Col 22 than CMC 40. Yield reduction for M Col 22 was 88.0% and 68% for CMC 40 (Table 7). Mealybug populations were higher on M Col 22 vs. CMC 40 (3.9 vs.3.0 on a 0 to 5 scale). In addition, production of planting material was reduced by 74 and 48%, respectively, for M Col 22 and CMC 40. These results support observations that mealybugs constitute a major threat to cassava production in their ability to significantly reduce yields.

Bio-ecological studies

Initial data (Cassava Annual Report, 1983) indicated that mealybugs randomly disperse from infested plants within cassava fields. This year, the influence of plant age on mealybug infestation was studied at Carimagua with natural infestations of the mealybug. When mealybug populations were low (December) there was a preference for older plants (Figure 3). But as the mealybug population increased, this preference diminished and with high populations there was no significant preference for plant age. Mealybug distribution within the plant was also affected by the overall density of mealybugs. When mealybug populations were low, distribution favored the lower leaves and growing points (Figure 4). However, as the mealybug population increased the population density shifted more toward the upper portion of the plant.

Mealybug dispersion on the cassava plant was also studied in the laboratory. Nymphal dispersion was greater when there was a large number of ovisacs (Figure 5). This indicates that competition plays a role in mealybug dispersion.

In another experiment observations were made on the movement of mealybugs from different sites of infestation. There was considerable dispersion of mealybugs in the first instar, especially for those placed on the lower regions of the plant (Figure 6). First instar nymphs placed on the upper leaves or in the terminal shoot tended to remain in these regions. There is only minimal movement of second and third instar nymphs and almost no movement of adults.

Life cycle studies

Four cassava varieties were selected for life cycle studies based on their reaction to mealybug populations under greenhouse screening; M Col 286 (susceptible), M Col 296 (very susceptible), M Col 263 (moderately resistant) and M Col 22 (resistant). There was no significant difference in the mealybug development among the four varieties tested. (The duration of the life cycle ranged from 55.6 to 59.9 days). Nor was there any significant difference in female oviposition and the size of nymphs and adults. These results indicate that although these varieties displayed varying plant damage symptoms to mealybug densities, there is no measurable effect on mealybug development. Therefore, it is probable that those varieties displaying greenhouse resistance are not actually resistant to mealybugs in the field, which indicates that greenhouse screening is not effective.

Mealybug toxin studies

Plant damage symptoms especially leaf and stem distortions indicate the possible presence of an insect toxin causing this reaction. On the theory that an insect toxin could be translocated from one plant part to another so that damage symptoms such as leaf and stem distortion would appear on the growing shoots due to mealybug feeding on the leaves, 30-45 day old potted cassava plants (M Col 22 and M Col 296) were infested in the greenhouse with 1, 5, 10, 20 and 25 first instar nymphs. These were confined to feeding on the lower stems to determine if toxins were translocated upward directly through stem tissue. Nymphs were also confined to upper leaves by enclosing them in 15 cm plastic petri dishes. The growing point of each plant was protected from nymphal

infestation by enclosing it in a plastic cylinder. Mealybug population in the confined areas ranged from 20-200 nymphs.

Results showed that mealybug infestations, regardless of population density, produced no evidence of a translocated insect toxin. No damage symptoms appeared in the growing shoot when mealybug feeding was confined to the leaves or the stem below the growing points. Even when cassava plants were placed in stress situations by withholding water for 4 or 5 days no damage symptoms appeared. These results suggest that if an insect toxin is involved it is not being translocated upward in the plant to the apical buds. The possibility that the toxin is localized to the immediate area of insect feeding was not, however, eliminated.

In a separate experiment, terminal growing points were infested with 5, 10, 15 and 20 mealybug nymphs and adult females. It was observed that damage symptoms are most pronounced when first instar nymphs recently emerged from the ovisac begin feeding in the terminal bud. One female with an ovisac is sufficient to cause damage symptoms to appear. This indicates that a localized toxin may be present.

Biological control

There is a wide complex of natural enemies of the cassava mealybugs. Systematic monitoring of mealybug populations at CIAT during 1984 has identified hymenopteran parasites previously unrecorded at CIAT. These were: *Anagyrus insolitus* Howard; *Apoanagyrus elgeri* Kerrich; and *Anagyrus putonophilus* Compare, all in the family Encyrtidae.

In addition, the hyperparasite *Prochiloneurus dactylopii* Howard (Encyrtidae) was found on mealybug parasites. The larvae of *Chrysopa* sp., a mealybug predator was observed to be parasitized by *Isodromus iceryae* Howard (Encyrtidae), and the larvae of *Ocyptamus* sp., a dipteran predator of the mealybug, was parasitized by *Pachyneuron albitius* Walken (Pteronalidae).

The mealybug *Epidinocarsis diversicornis* (= *Apoanagyrus diversicornis*) parasitized the cassava mealybug, *Phenacoccus herreni* at Carimagua (Cassava Annual Report, 1983) and was released in a CIAT cassava field. A colony of this parasite was established and its biology and behavior were studied. Experiments were conducted to identify an adequate diet for sustaining large numbers of parasite adults. Adults receiving no nourishment survived an average of only 3.8 days. Those parasites receiving solid sugar survived 9.3 days. A diet consisting of 50% honey sustained parasite adults for an average period of 20.2 days (Table 8).

The life cycle of *E. diversicornis* was studied in the laboratory (T. 25°C, RH 70%) in the second and third nymphal stages of *P. herreni*, *E. diversicornis* is parthenogenic and females were allowed to parasitize second and third instar nymphs. these parasitized nymphs were maintained on cassava leaves in plastic petri dishes. The duration of the parasitoid development stage from oviposition to parasitoid emergence was 18.3 days when parasitism occurred in second instar

nymphs,and 17.5 days when it occurred in third instar nymphs (Table 9). This is a relatively short cycle and should syncronize well with mealybug populations.

Studies were also conducted to determine what mealybug instars are the preferred host for the parasitoid E. diversicornis. Observations show that the parasitoid locates the mealybug with its antennae, attempts to oviposit, and does so if the host is suitable. The female parasitoid will attempt and can achieve parasitism on all developmental stages of the mealybug. However, the third instar females and adult females (Table 10) are preferred. Thirty three percent of parasitism occurred in third instar nymphs and 31% in adult females. Parasitism also occurred with first and second instars with 11.2 and 15.6% respectively. Second instar males and male cocoons were the least preferred with 8.0 and 0.7% parasitism, respectively.

Cassava Hornworm

Studies on yield losses, bio-ecology and biological control of the cassava hornworm (Erinnyis ello (L), continued during 1984. There are several plant growth and environmental factors that are associated with yield reductions due to hornworm attack. (These are outlined in the 1983 Cassava Annual Report.) Previous studies have also shown that consecutive hornworm attacks, where the second attack occurs one month after the previous one, will result in very severe yield reductions (Cassava Annual Report, 1983). Consecutive attacks of the hornworm have been reported from several cassava growing areas, especially Brazil and Colombia. This has usually led to drastic control measures, envolving several applications of insecticides. These, in addition to being costly, are also detrimental to natural enemies, which, in turn result in more frequent hornworm attacks.

Hornworm damage was simulated by removing 100% of the foliage at different periods. Plants of different ages were completely defoliated once, or twice, with the second defoliation one month after the first. Experiments were conducted in Santander de Quilichao (Cauca), a site with poor soils, and at CIAT-Palmira a fertile site. The number of fifth instar larvae needed to cause the defoliation was estimated from data on leaf area and E. ello consumption rates. Three clones of cassava were used: M Mex 59; CM-305-41; and HMC 2 with wide, intermediate and narrow leaves, respectively. Yield loss in the poor soil site reached 64% when there were two consecutive defoliations and 46% after one defoliation (Tables 11 and 12). In the fertile soils site losses reached 47 and 25.5% with two and one defoliation, respectively (Tables 13 and 14). On fertile soils the average yield loss was 12.7 and 31.6% while on the poor soil it was 32.2 and 49.5% for one and two defoliations, respectively. Yield losses due to hornworm attacks are greater on poor soils than more fertile soils. In addition, the yield losses due to two consecutive defoliations can be much more severe than with only one defoliation.

In general, yield loss results on fertile soils were not as consistent as those on poor soils. With one defoliation on fertile soils losses ranged from 0 to 25.5% with no obvious relation to plant age, and with one defoliation on poorer soils, yield losses were greater

during the first four months of the plant cycle and lowest during the latter months.

As a rule, starch content was higher on the fertile soils than the poorer soil after hornworm attacks. In addition it was usually higher when only one defoliation occurred but this difference was not significant on the poor soil.

There is a relationship between the number of larvae needed to defoliate a cassava plant and the vigor of the plant. More larvae per plant are needed for complete defoliation on the fertile soil than the poor soil as there is more foliage on plants growing in fertile soils (Table 11 to 14). In general, fewer larvae are needed to defoliate a plant during the second attack when the attacks occur consecutively.

Whiteflies

The whitefly, Aleurotrachelus socialis causes considerable yield losses in cassava and may transmit virus diseases. Evaluations of the CIAT germplasm bank for resistance to this species have been carried out for the past several years. At present a total of 1200 clones have been evaluated at the ICA-Nataima, Espinal, and Tolima stations in Colombia. During 1984, 150 additional clones were evaluated and 21 or 14%, were selected for further study (Table 15).

Evaluations are done using three damage scales; one measures the overall whitefly infestation related to the percentage of the total plant infested with whitefly stages. The second measures the level of pupal development based on the number of pupae per leaf, and the third describes and measures the level of plant damage related to damage symptoms caused by whitefly feeding.

Results of this year's evaluation (Table 15) show that whitefly populations were very high on all varieties, even those selected for further study. All leaves on the plants contained some stages of whitefly development. The 21 clones selected showed low pupal infestation and reduced damage symptoms. Pupal infestations were 2.0 or lower (based on a 0-5 scale) and damage symptoms were from 1.0 to 1.5 (based on a 0-5 scale) for most of the 21 selected clones.

These results show that although adult populations were high on resistant clones, pupal development was reduced and plants were not severely damaged. Susceptible varieties displayed both higher pupal counts and severe damage symptoms. This indicates that some mechanism of resistance or tolerance is present in the selected clones.

An undescribed species of whitefly was found feeding on cassava in the Tolima area; this was identified as Paraleyrodes sp. by the Systematic Entomology Laboratories, IIBIII, USDA.

Stemborers

Numerous species of stemborers have been reported attacking cassava. The most important stemborers belong to the orders Coleoptera and Lepidoptera. Previous Cassava Annual Reports (1980, 1981, 1982 and 1983), have described research results for two species Chilomima clarkei

(Lepidoptera) and Lagochirus araneiformis (Coleoptera: Cerambicidae). Both species can cause considerable damage to cassava stems and consequently planting material.

During the past year studies with L. araneiformis concentrated on its biology, morphology, behavior and the economic damage caused by the species. The life cycle was also studied in the laboratory and under field conditions. Two methods were utilized to study the larval stage in the laboratory (28.4°C and 65% RH); the first used fresh, recently cut stem pieces while the second consisted of dried, stored stem pieces.

Results of the two laboratory methodolcgies differed considerably, especially during the larval stage. Using the first methodolcgy the life cycle was 3.1, 87.6 and 7.6 days for the egg, larval and pupal stages respectively; using the second methodology the results were 3.1, 54 and 7.6 days. Females lived an average of 45.9 days and males 71.9. The total average duration for the female and male cycle with the first methodology was 144 and 170 days; with the second methodology it was 110 and 136 days respectively.

Under field conditions the duration of egg to adult was an average of 128 days with a range of 86-194 days. Longevity of females was 92 days and males 90; consequently adult longevity was greater in the field than in the laboratory. The total life cycle in the field was 218 days for the females and 219 days for the male which is considerably longer than results obtained in the laboratory. Two factors probably influenced these differences: (1) the environmental conditions of the field with its fluctuating temperatures; (2) the field studies were done with growing plants whereas laboratory studies were done with stem cuttings.

Behavioral studies show that females can oviposit without copulation, however, the resulting eggs are infertile. The average preovipositional period for fertilized females was 9.7 days and oviposition lasted an average of 28.8 days (Range of 13-62). Females oviposited an average of 150 eggs fluctuating between 2.8 and 8.4 per day, decreasing as females aged. Oviposition was greater during the night (57%) and early morning (33%) with a few eggs oviposited during late morning (10%). No oviposition was observed between 12 am and 6pm.

Recently emerged larvae can be found feeding in the bark of cassava stems toward the base of the plant. In subsequent instars they bore into the lignified position of the stem, eventually feeding in the pith region where pupation occurs. The number of larval instars may vary depending upon the conditions. Results with the first methodology showed a range of 7-9 instars, while the second resulted in 4-8 larval instars before pupating. This phenomenon is not uncommon among stemborers and similar results were obtained with Chilomima clarkei (Cassava Annual Report, 1980).

Economic damage studies

Studies were initiated to determine the yield reductions caused by this pest. Infested and non-infested cuttings were planted in the field, in two separate experiments. Germination and yield were

recorded. Results show that the yield reduction fluctuated between 4 and 20.6% for the two experiments (Table 16) and the percentage of infested plants varied from 78.3 to 84%. Germination was high, 90.6 and 98.8%, respectively, for the infested and uninfested plants in spite of the high infestation rate. Plant development was not noticeably affected by L. araneiformis infestation; there was no significant difference between plant height and number of selected cuttings. These results indicate that although L. araneiformis may occasionally cause localized damage it is probably not a serious pest of cassava. Previous studies have shown that the pest populations can be controlled through phytosanitary practices and treatment of planting material.

Termites

Termites are a problem on cassava primarily in the tropical lowlands. They feed on propagation material, on roots, or on lower stems. During harvest of the Media Luna ecosystem trial during 1984 varieties were evaluated for termite damage (see Cassava Annual Report, 1982 for previous results). An average of 3.4% of the harvestable roots were damaged by termites and 98.3% of the lower stems or "necks" (Table 17).

A total of 31 clones were evaluated on the Colombian North Coast. Clones grown by farmers on the coast (Ecosystem 1) had the lowest termite damage to the roots, 0.5%, while the regional high altitude varieties (Ecosystem 5) had the highest 8.8% (Table 17).

Cassava Pest Complex

A measurement of the insect and mite complex on cassava at CIAT has been carried out for four crop cycles. The effect of this complex on cassava root and stake yield has been recorded (see Cassava Annual Report, 1981 and 1983). The four varieties used in the experiment were CMC 40, M Col 113, M Col 22 and M Col 1684. The major pests that attacked these varieties throughout the 1984 growing cycle were mites (Mononychellus, Oligonychus and Tetranychus species), Thrips, mealybugs (Phenacoccus herreni). There was also some lace bug damage. In general, insect and mite populations were low throughout most of the year although mite populations were slightly higher than the previous year. Thrips damage was moderate to high on varieties M Col 1684 and CMC 40, low to moderate on M Col 22 and very low on M Col 113. Thrips damage was probably the major cause of yield reductions that were recorded on CMC 40, M Col 22 and M Col 1684. Reductions of 28.9, 23.3 and 24.3% were recorded for these three varieties. There was no yield reduction for M Col 113, which is resistant to thrips and the traditional variety grown in the Department of Valle.

Table 1. A comparison of cassava root damage caused by Cyrtomenus bergi when cassava is planted in monoculture, intercropped with crotalaria, treated with a pesticide and the use of a high HCN variety.

Treatment	Yield t/ha	% Root damage	Damage level (0-5 scale)
Cassava (Chiroza) Monoculture	38.4 b*	61.2 a	3.5
Cassava (Chiroza) + Crotalaria	29.9 c	3.7 c	0.5
Cassava (Chiroza) + Pesticide [a]	40.6 b	30.0 b	2.5
Cassava (M Col 1684) + Pesticide	56.1 a	0 d	0
Cassava (M Col 1684) without pesticide	57.0 a	0 d	0

[a] Dimethoate 2 cc/lt water

* Numbers in the same column are not significantly different at the 0.05% level of the Duncan Multiple Range Test.

Table 2. The yield of selected mite resistant hybrids under low mite densities at CIAT.

Genotype	Yield t/ha	% Starch	Planting material/plant
C G 7-56	34.0 a*	36.2 a	17.2 a
C G 5-79	31.7 ab	35.3 ab	16.7 a
C G 4-81	28.2 bc	35.2 bc	14.8 ab
C G 5-78	25.1 c	35.1 bc	14.5 ab
M Col 22	18.5 d	34.4 cd	11.8 bc
C G 5-99	12.3 e	33.9 d	8.5 c

* Numbers in the same column followed by the same letter(s) are not significantly different at the 5% level of the Duncan Multiple Range Test.

Table 3. Species of the family phytoseeidae found feeding on cassava phytophagous mites in the Department of Valle, Colombia.

Amblyseius aeriales (Muma, 1955)

Amblyseius largoensis (Muma, 1955)

Amblyseius chiapensis (De Leon, 1961)

Amblyseius herbicolus (=deleoni) (Chant, 1959)

Galendromus annectens (De Leon)

Galendromus heveolus (= floridanus) (Chant, 1959)

Neoseiulus anonymus (Chant & Baker, 1965)

Typhlodromalus aripo De Leon, 1967

Typhlodromalus peregrinus (Muma, 1955)

Typhlodromalus neoturnus Denmark & Muma, 1973

Typhlodromalus limonicus (Garman & MacGregor, 1956)

(= Amblyseius limonicua (Garman & MacGregor, 1956)

Tabla 4. Life cycle of Neoseiulus anonymus (Phytoseiidae) feeding on Tetranychus urticae (Tetranychidae) in the laboratory (25° C, 60 ± 10% RH).

Biological stage	N	Maximum	Minimum	Average
Egg	60	72	24	50.6
Larvae	56	24	4	13.1
Protonymph	56	48	8	24.7
Deutonymph	56	56	8	24.5
Total immature				112.8 (4.7 days)
Adult longevity (in days)				
Female	41	30	8	17.9
Male	10	20	12	15

Table 5. Life cycle of Neoseiulus anonymus (Phytoseiidae) feeding on Mononychellus progresivus (Tetranychidae) in the laboratory (25° C, 60 ± 10% RH).

Biological stage	N	Duration in hours		
		Maximum	Minimum	Average
Egg	60	72	24	50.1
Larvae	58	24	4	13.4
Protonymph	51	44	8	24.1
Deutonymph	50	48	9	24.7
Total immature				112.2 (4.6 days)
Adult longevity (in days)				
Female	50	24	4	9.4
Male	17	11	4	6.7

Table 6. Life cycle of Typhlodromalus limonicus (Phytoseiidae) feeding on Mononychellus spp. (Tetranychidae) in the laboratory (20° C, 60 ± 10% RH).

Biological stage	No.	Duration in hours		
		Maximum	Minimum	Average
Egg	57	96	26	50.8
Larvae	55	96	6	38.6
Protonymph	45	72	18	35.8
Deutonymph	40	120	9	38.0
Total immature				163.2 (6.8 dias)
Adult longevity (in days)				
Female	25	19	6	12
Male	9	19	11	12.5

Table 7. The effect of mealybug (Phenacoccus herreni) attack on root yield and production of planting material in cassava.

Variety	Treatment	Root yield (t/ha)	Stakes plant	Mealybug population grade[c]	Mealybug pupae grade[c]
	Mealybugs absent a[a]	18.6	1.5	0.2	0.0
M Col 22		(88.4)[b]	(73.9)		
	Mealybugs present [b]	2.2	5.6	3.9	4.1
	Mealybugs absent [a]	14.2	8.9	0.1	0.0
CMC 40		(67.9)	(48.3)		
	Mealybugs present [b]	4.6	4.6	3.0	3.1

[a] Values with the same letter are not significantly different at 5% level of the Duncan Multiple Range Test.

[b] Percentage of difference

[c] Scale

Table 8. Adult longevity of the mealybug parasitoid Epidinocarsis diversicornis H. feeding on three diets in the laboratory (T. 25° C, RH 70%).

Adult diet	No. observ.	Adult longevity (days) Minimum	Maximum	Average	S.D.
No feeding	25	1	6	3.8	1.4
Solid sugar	25	3	16	9.3	3.0
Solution of honey + water (50%)	22	6	49	20.2	14.5

Table 9. Preference of the parasitoid Epidinocarsis diversicornis H. for parasitism of the different biological stages of the mealybug Phenacoccus herreni in the laboratory (T. 25° C, RH 70%).

INSTAR	Encounter		Intent to oviposit		Oviposition	
	No.	%	No.	%	No.	%
I	119	11.5	51	10.6	34	11.2
II	120	11.6	71	14.7	43	15.6
II	101	9.8	33	6.8	22	8.0
III	256	24.8	156	32.3	92	33.3
Coccon	97	9.4	4	0.8	2	0.7
IV	340	32.9	168	34.8	86	31.2

Table 10. The development of the parasitoid Epidenocarsis diversicornis H. on two instars of its hots Phenacoccus herreni C. in the laboratory (T. 25° C, RH 70%).

Biological stage	Instar of mealybug	No. observ.	Duration (days)			
			Minimum	Maximum	Average	S.D.
Oviposition to mummy Formation	II	30	7.0	13.0	9.89	2.33
	III	30	4.0	14.0	9.23	2.64
Mummy to adult Parasitoid emergence	II	30	7.0	10.0	8.42	1.54
	III	30	5.0	12.0	8.25	1.60
Total parasitoid Cycle	II	30	13.0	22.0	18.32	3.0
	III	30	11.0	21.0	17.48	2.66

Table 11. The effect of simulated hornowrm (Erinnyis ello) damage[a] (two consecutive attacks) at different plant ages on the yield of three cassava varieties[b] and estimated number of larvae needed for defoliation[c], Santander de Quilichao.

Plant age (mo)	Root yield t/ha	% reduction	Leaf area cm^2 X of one plant	No. X Larvae	Rainfall between defoliations (mm)
			(a) (b)	(c) (d)	
1 - 2	20.0 a*	28.8	1.971 - 3247	1.8 - 3.0	80 - 109
2 - 3	11.3 b	59.7	7.396 - 1895	6.7 - 1.7	292
3 - 4	10.1 b	64.1	14.438 - 5755	13.1 - 5.3	214
4 - 5	15.4 b	45.2	15.653 - 6289	14.2 - 5.7	82
Control	28.1 a	-	-	-	-

[a] 100% defoliation

[b] CM 305-41 (medium leaf)
M Mex 59 (wide leaf)
HMC 3 (narrow leaf)

[c] One larvae consumes 1,100 cm^2

(a) (c) first defoliation
(b) (d) second defoliation
Feb. 82 - Nov. 82

[d] (p) Rainfall during 57(7), 0(8), 150(19), 251(10), 296(11).

* Numbers in the same column followed by the same letter are not significantly different at the 5% level of the Duncan Multiple Range Test.

Table 12. The effect of simulated hornworm (*Erinnyis ello*) damage[a] (one attack) at different plant ages on the yield of three cassava varieties[b] and estimated number of larvae[c] needed for defoliation[d], CIAT.

Plant age (mo)	Root yield t/ha	% reduction	Leaf area cm^2 X of one plant	No. X larvae	Rainfall between defoliation (mm)
1	30.1 b*	23.2	4.865	4.4	66.9
2	39.2 a	0.0	16.922	15.4	23.3
3	37.9 a	3.3	16.889	15.3	5.6
4	35.1 ab	10.5	20.645	18.8	13.7
5	20.2 b	25.5	16.346	15.0	54.5
7	30.1 b	23.2	28.495	26.0	231.5 d
9	31.9 a	3.3	26.336	24.0	189.2 d
T	39.2 a	-	-	-	

[a] 100% defoliation

[b] CM 305-41 (medium leaf)
M Mex 59 (wide leaf)
MMC 2 (narrow leaf)

[c] One larvael consumes 1100 cm^2
[d] Two months accummulated

* Numbers in the same column followed by the same letter are not statistically different at the 5% level of the Duncan Multiple Range Test.

Table 13. The effect of simulated hornworm (*Erinnyis ello*) damage[a] (two consecutive attacks) at different plant ages on the yield of three cassava varieties[b] and estimated number of larvae needed for defoliation[c], CIAT.

Plant age (mo)	Root yield t/ha	% reduction	Leaf area cm^2 X of one plant	No. X Larvae	Rainfall between defoliations (mm)
			(a) (b)	(c) (d)	
1 - 2	22.8 c*	42.4	2.379 - 2.164	2.2 - 2.0	86.3 - 12.2
2 - 3	25.1 cb	36.6	11.984 - 2.389	11.0 - 2.2	13.8
3 - 4	33.6 ab	15.2	10.195 - 10.467	9.3 - 9.5	31.2
4 - 5	20.9 c	47.2	17.312 - 12.502	15.7 - 11.4	146.3
7 - 8	28.3 cb	28.5	25.721 - 19.064	23.4 - 17.3	233.8 (2)
8 - 9	32.5 ab	17.9	32.519 - 18.620	29.6 - 16.9	26.0
Control	39.6 a	-	-	-	30.5

[a] 100% defoliation

[b] CM 305-41 (medium leaf)
M Mex 59 (wide leaf)
HMC-2 (narrow leaf)

[c] One larvae consumes 1100 cm^2
(a) (c) first defoliation
(b) (d) second defoliation
(May-83 - Feb. 84)

* Numbers followed by the same letter are not significantly different at the 5% level of the Duncan Multiple Range Test.

Table 14. The effect of simulated hornworm (*Erinnyis ello*) damage[a] (one attack) at different ages on the yield of three cassava varieties[b] and estimated number of larvae[c] needed for defoliation, Santander de Quilichao.

Plant age (mo)	Root yield t/ha	% reduction	Leaf area cm^2 X of one plant	No. X larvae	Rainfall between defoliations (mm)
1	16.9 b	34.2	4.927.0	4.5	176
2	15.5 b	39.7	9.119.0	8.3	298
3	13.8 b	46.3	14.367.0	13.0	251
4	14.7 b	42.8	13.870.0	12.7	97
5	20.2 a	21.4	9.501.0	8.6	35
7	22.1 a	14.0	3.691.0	3.4	20
9	18.7 ab	27.2	11.200.0	10.2	173

[a] 100% defoliation

[b] CM 305-41 (medium leaf)
M Mex 59 (wide leaf)
HMC 2 (narrow leaf)

[c] One larvae consumes 1100 cm^2

Table 15. Selected varieties (150 varieties evaluated) displaying a potential for resistance to the whitefly (*Aleurotrachelus socialis*) attack at Tolima, Colombia.

Variety	Population level[a]	Pupal level[b]	Damage level[c]
M Col 1773	5.0	2.0	2.0
1695	5.0	2.0	2.0
1699	5.0	2.0	2.0
1700	5.0	2.0	1.0
1706	5.0	2.0	1.5
1694 L	5.0	2.0	1.5
1739	5.0	2.0	1.0
1886	5.0	1.0	1.0
1788	5.0	2.0	1.5
1892	5.0	2.0	1.0
1826	5.0	2.0	1.0
1770	5.0	2.0	1.0
1691	5.0	2.0	2.0
1900	5.0	2.0	2.0
1912	5.0	2.0	2.0
1834	5.0	2.0	1.5
1820	5.0	2.0	1.0
1894	5.0	2.0	2.0
1813	5.0	2.0	1.5
1903	5.0	2.0	1.5
1896	5.0	2.0	1.0

[a] Infestation level = 0-5 scale based on percentage of leaves infested with whitefly stages.

[b] Pupal level = 0-5 scale based on number of pupae per leaf. 1 = 1-50, 2 = 51-100, 3 = 101-250, 4 = 251-500, 5 = 500.

[c] Damage grade = 0-5 scale. 0 = no damage to 5 = severe plant wilting, defoliation and heavy sooty mold.

Table 16. The effect of cassava cuttings infested with *Lagochirus araneiformis* on yield and germination, CIAT - Palmira.

Treatment			
Presence of *Lagochirus*	Yield t/ha	% Reduction	% Germination
		Experiment No. 1	
+	8.7	20.6	90.6
-	11.0		96.7
		Experiment No. 2	
+	18.2	3.8	98.8
-	18.9		97.5
		Average Experiments 1 + 2	
+	13.5	10	94.7
-	14.9		97.1

Table 17. Varietal reaction to termite attack in cassava roots and lower stems at Media Luna (Ecosystem 1), Colombia, during 1983-1984.

Varietal group	Number of varieties	% Roots attacked			% Lower stems attacked		
		Minimum	Maximum	Average	Minimum	Maximum	Average
Regional coastal varieties (Ecosystem 1)	7	0.0	3.3	0.5	96.3	100	98.7
Regional upland varieties (Ecosystem 5)	4	0.0	35.3	8.8	82.5	100	95.6
Other Colombian varieties	7	0.0	9.8	3.9	93.0	100	99.0
Hybrids	8	0.12	9.1	3.0	93.3	100	98.8
Non-Colombian varieties	8	0.0	2.3	0.9	96.7	100	99.2
X Totals	68	0.02	12.0	3.4	92.4	100	98.3

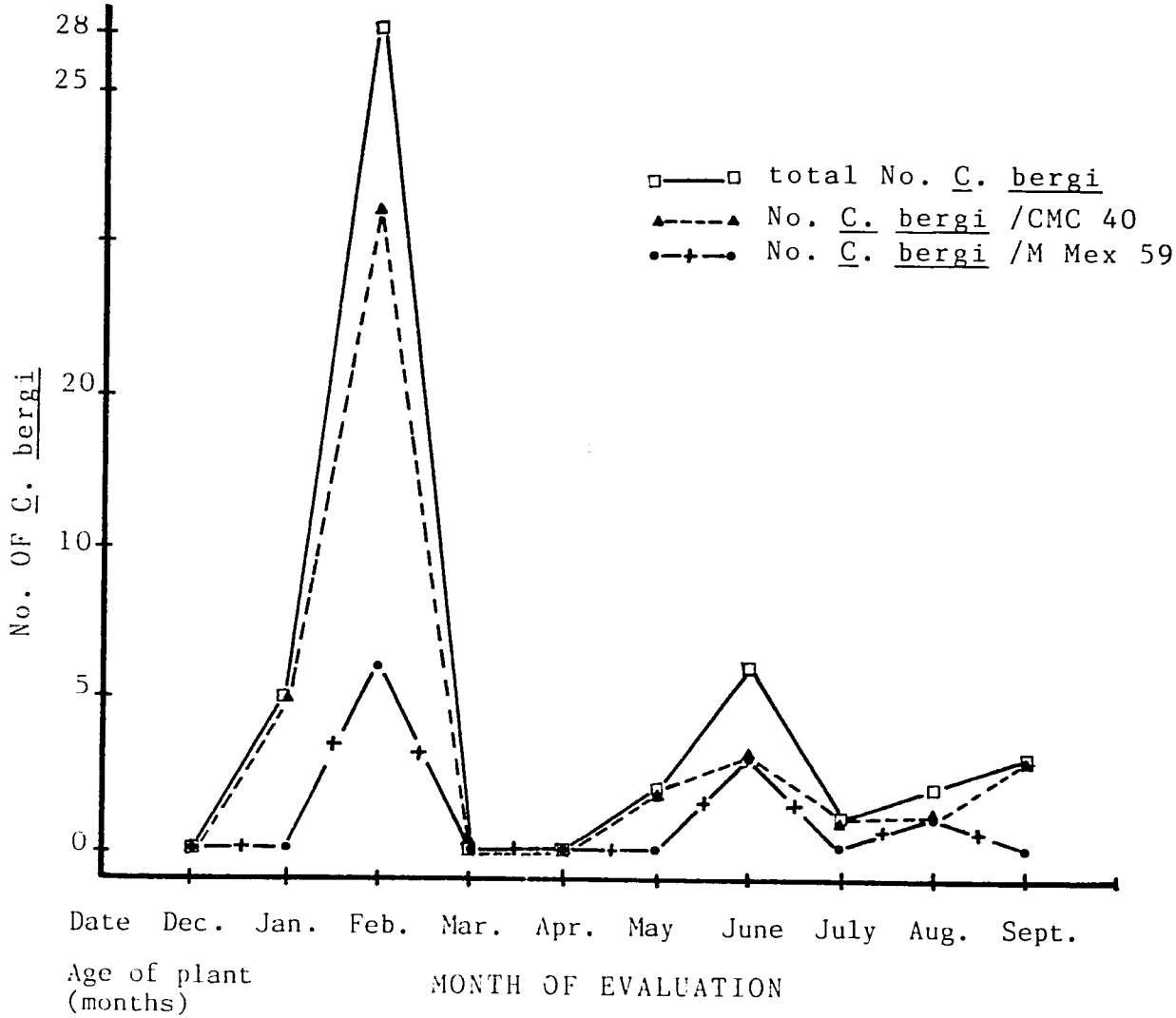


Figure 1. Populations of Cyrtomenus bergi associated with cassava roots (varieties CMC 40 and M Mex 59) over a 10 month period at Santander de Quilichao.

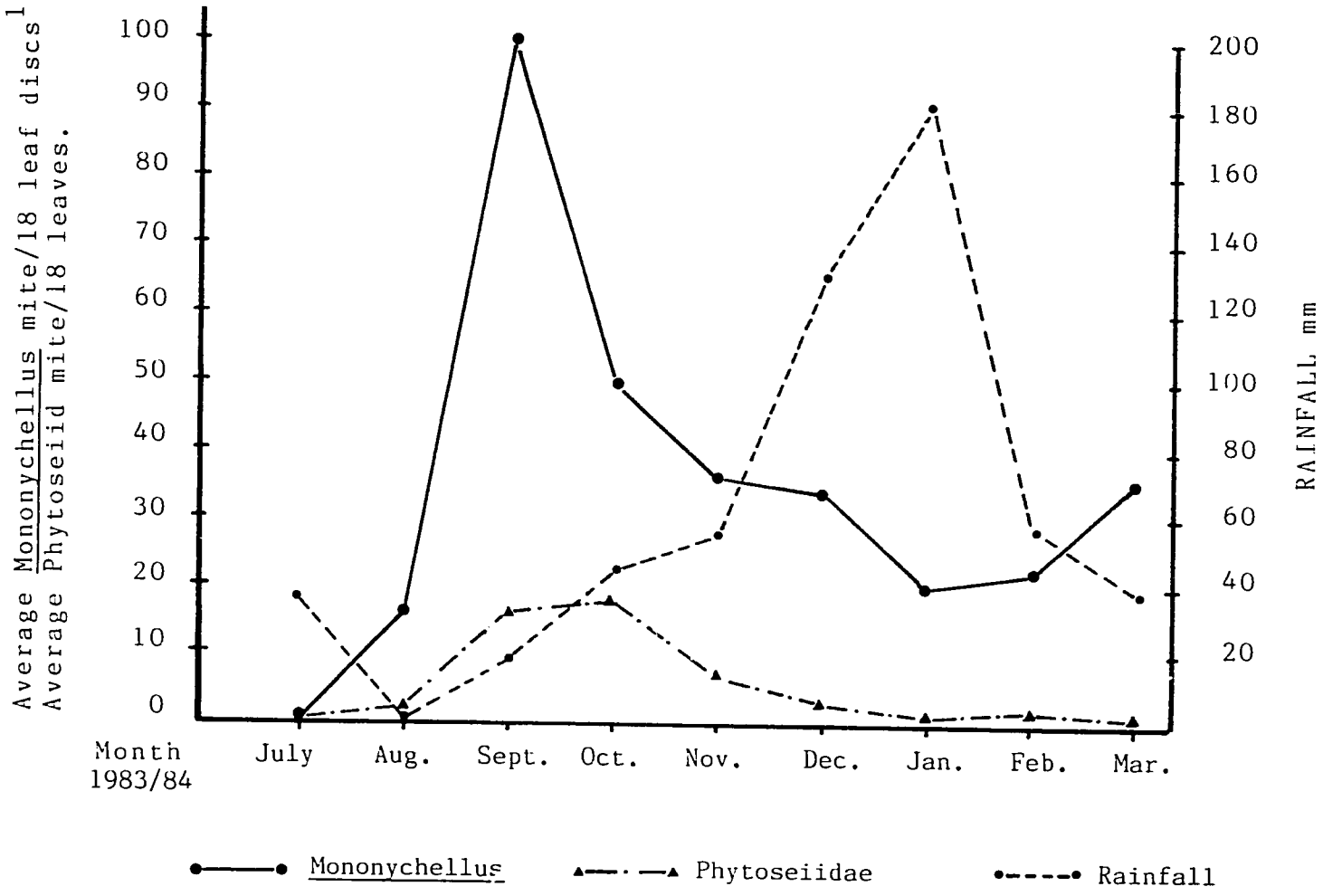


Figure 2. A comparison of populations of Mononychellus mites with Phytoseiidae mite predators and rainfall on selected cassava hybrids at CIAT during a 9 month period (1983-1984).

(1) 1 disc = 2.54 cm^2 leaf area

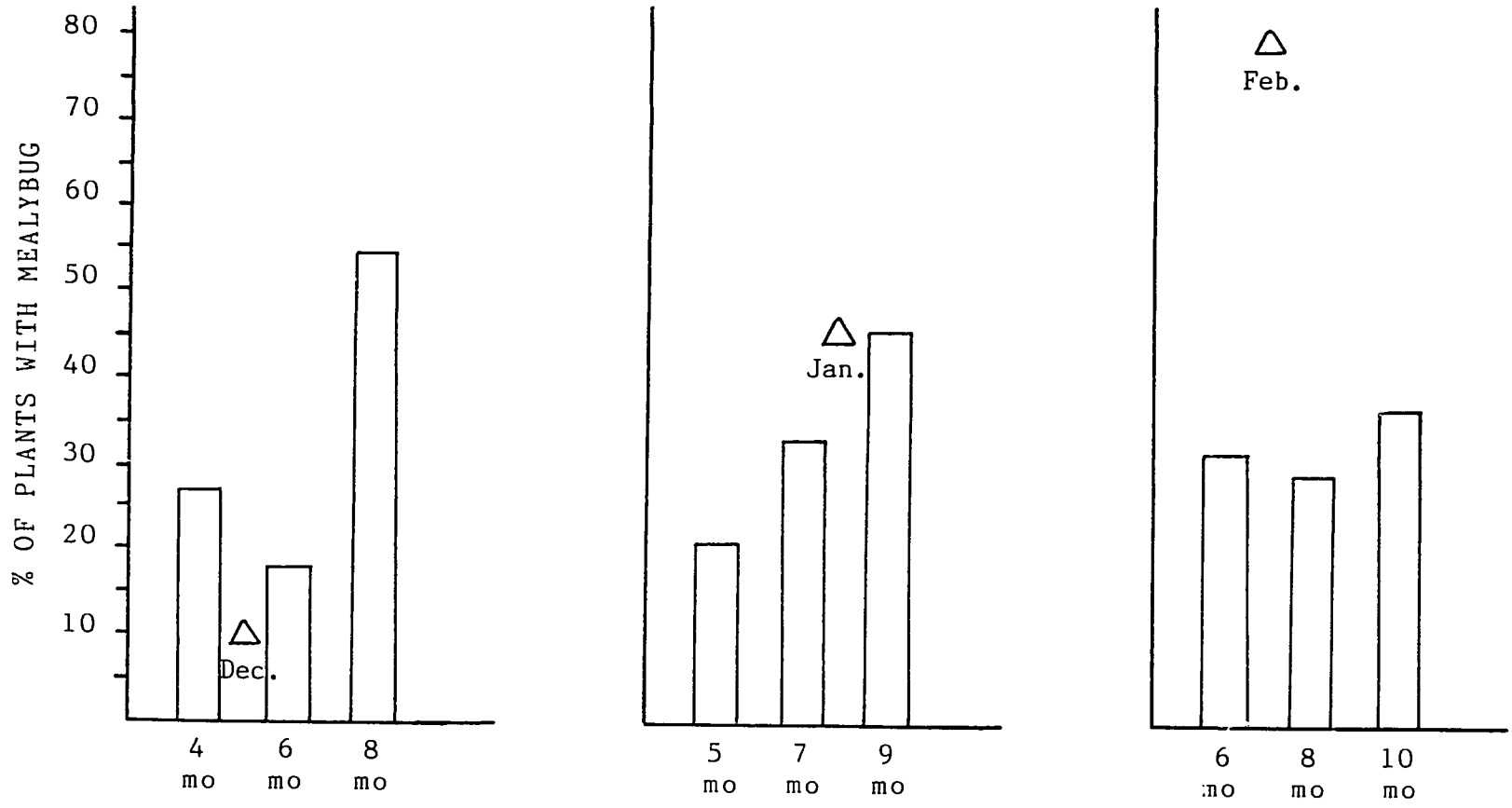


Figure 3. The correlation between level of mealybug (Phenacoccus herreni) population (△) and preference for cassava (M Ven77) plant age with natural infestations at Carimagua.

△ = Mealybug population

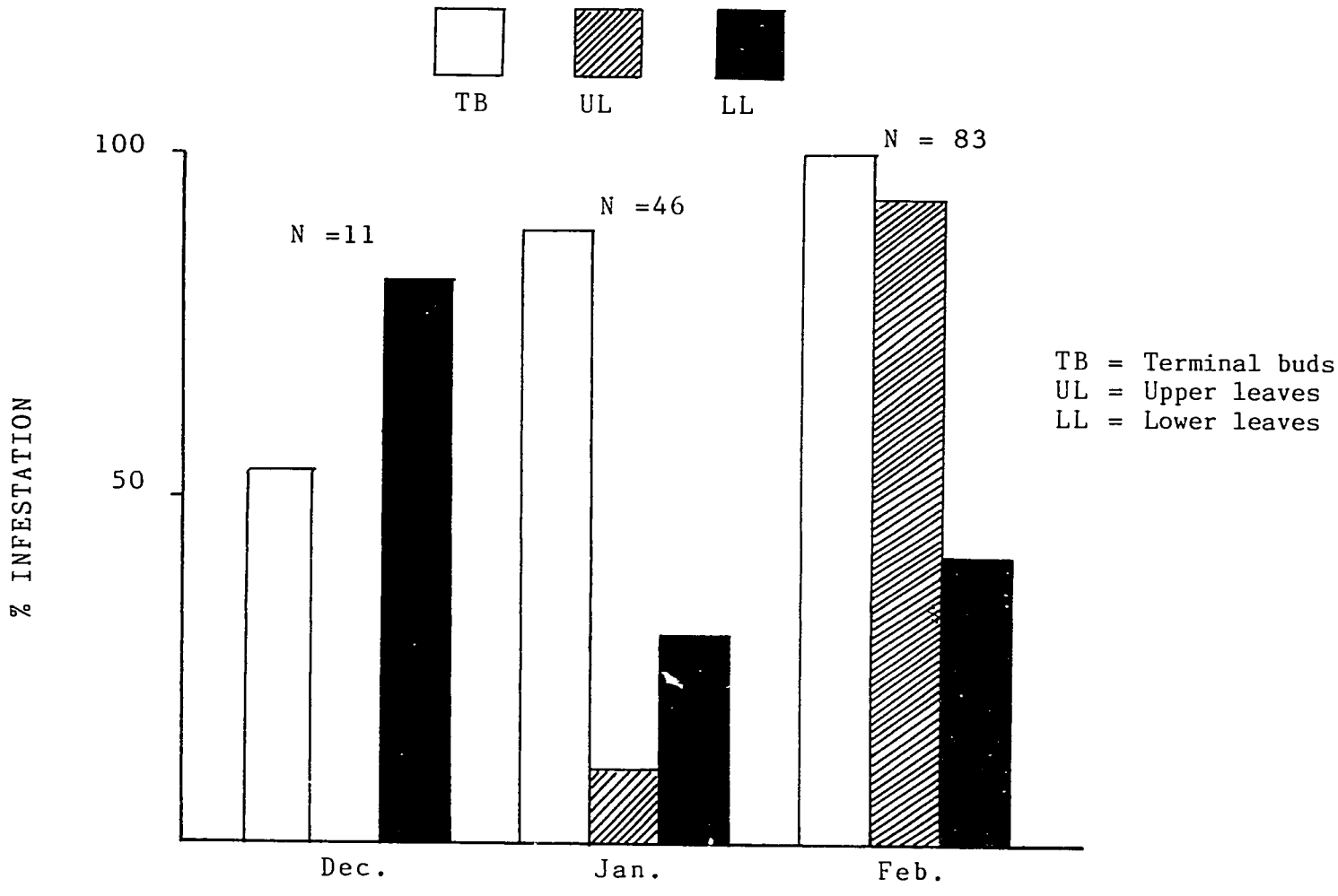


Figure 4. Distribution of mealybug (Phenaccus herreni) populations on the cassava plants (M Ven 77) with natural field infestations at Carimagua.

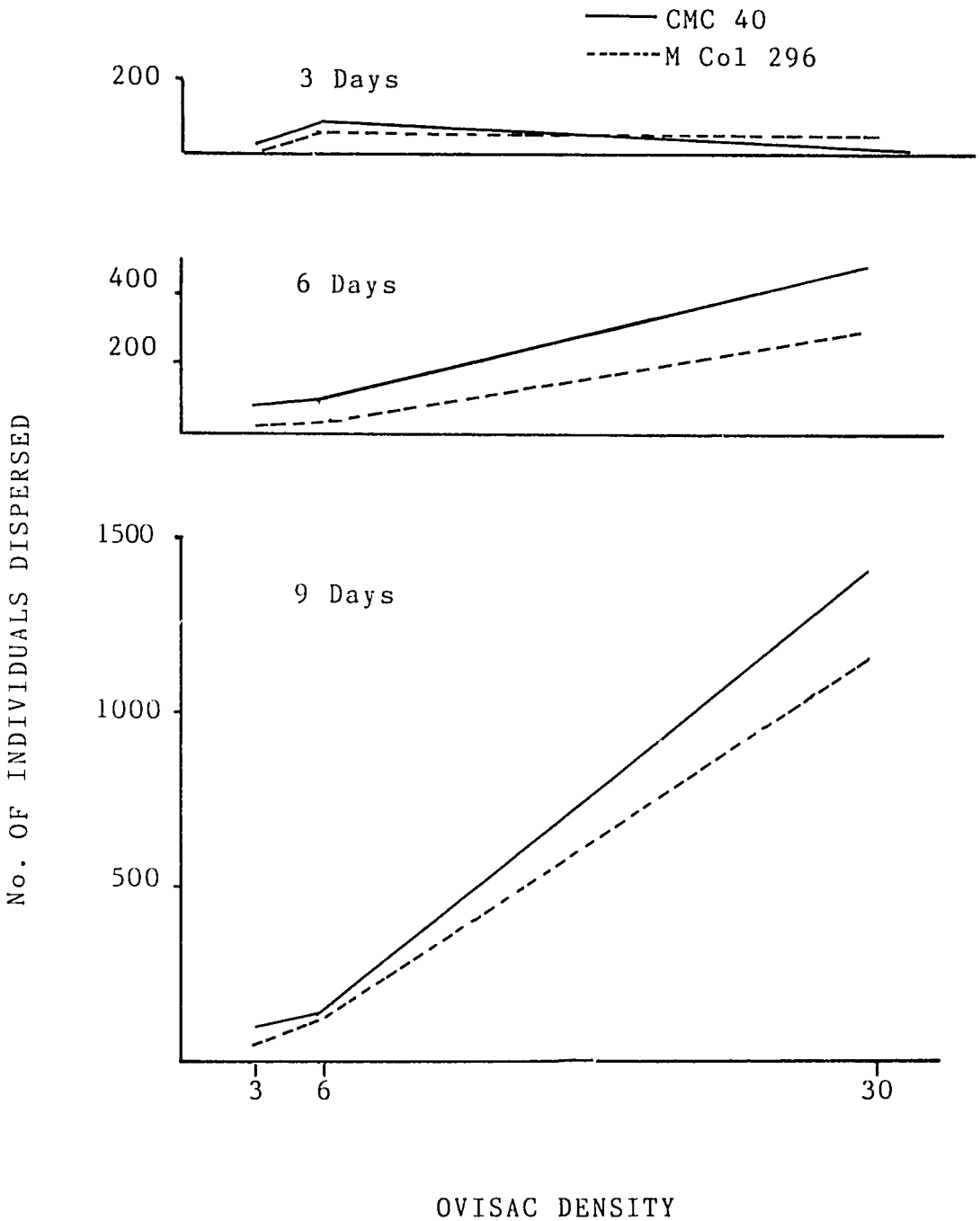


Figure 5. The correlation between the number of mealybug (Phenacoccus herreni) ovisacs infesting a cassava plant and the number of 1st. instar nymphs dispersed throughout the plant 3,6, and 9 days after infestation on varieties M Col 296 and CMC 40.

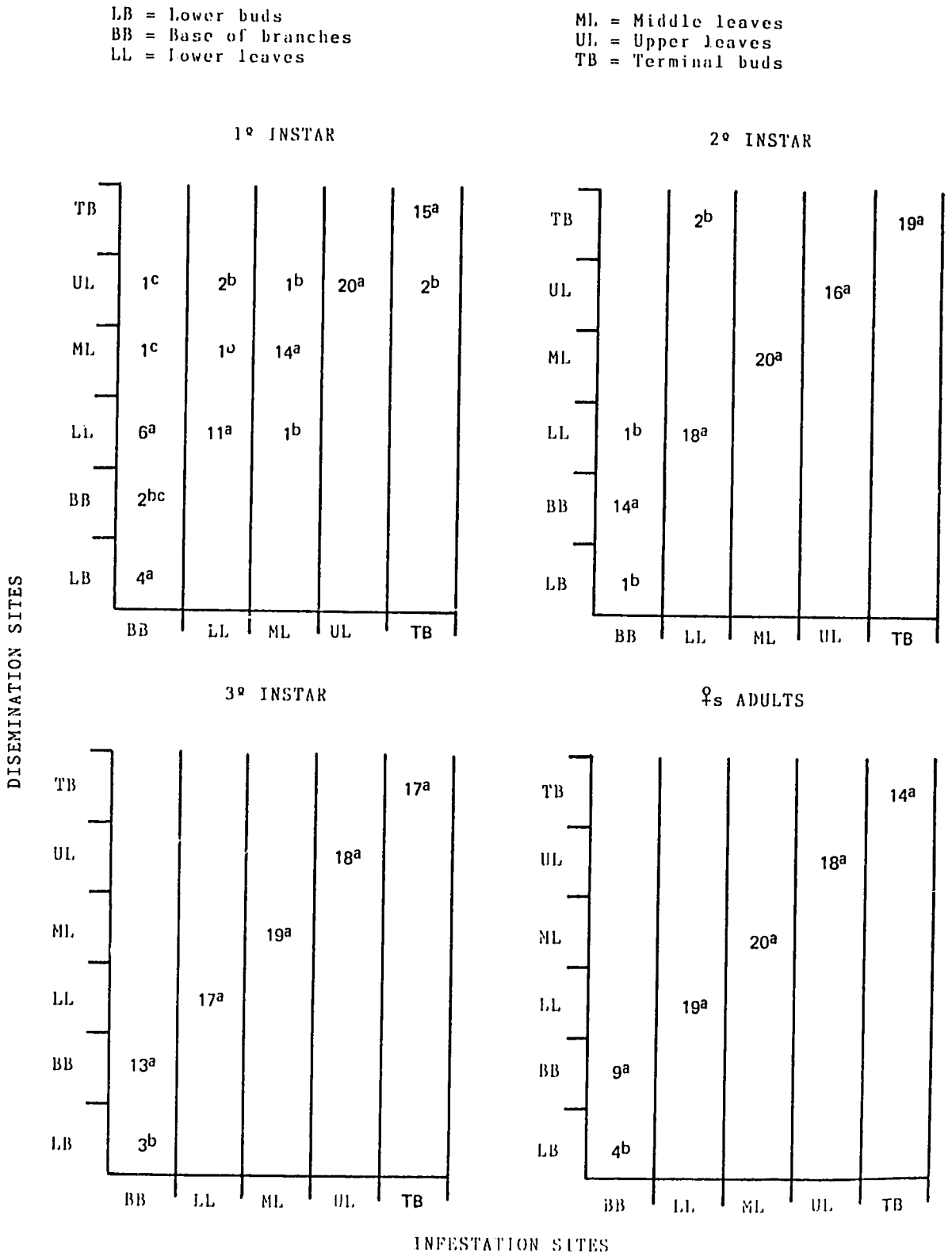


Figure 6. Disemination of mealybug (Phenacoccus herreni) of three instars and adult females on a cassava plant from five different infestation zones (Var. M Col 296).

GERMPLASM DEVELOPMENT

Germplasm Introduction and Evaluation

During 1984 CIAT signed an agreement with the International Board for Plant Genetic Resources (IBPGR) which officially assigns responsibility to CIAT for conservation of cassava germplasm in Latin America. New collections were introduced from Costa Rica, Guatemala, Panama and the Philippines, bringing the total number of accessions in the collection to 3,680 (Table 1). The entire collection continues to be maintained in the field, while at the same time the *in vitro* conservation of all accessions nears completion (see the Genetic Resources report).

There is normally a 1-2 year delay from the time of introduction to CIAT as *in vitro* cultures until new accessions are processed through phytosanitary observation and multiplication for multi-site evaluation. A major Brazilian collection brought from the national cassava center at Cruz das Almas (Centro Nacional da Pesquisa da Mandioca e Fruticultura) (CNPMF) is being evaluated in three ecosystems (edaphoclimatic zones 1, 2 and 3; see Table 2). A major interest of Brazilian scientists is to have disease resistance ratings for this material. The evaluations in Carimagua, Meta, provide heavy pressure for both bacterial blight (CBB) and superelongation disease (SE). Although the frequency of resistant clones is very low (typical of the germplasm collection as a whole) a few clones have good resistance levels (Tables 3 and 4). In Media Luna, Magdalena (with low rainfall, long dry season) many of these accessions show promise and 13 have been included in the advanced yield trial. These new introductions are adding important new genetic diversity to the breeding populations.

Parental Selection and Recombination

Extensive evaluations of the landraces of cassava have shown that few existing varieties meet the combined requirements for adaptation, resistance, plant type, yield potential and root quality under intensified production systems. Thus, CIAT emphasizes hybridization and selection to produce improved cassava clones.

Three distinct but related systems are utilized for selection of parents: (1) performance *per se* of a clone in a given edaphoclimatic zone; (2) general and specific combining ability as measured by performance of half sib and full sib progenies, respectively; and, (3) selection of parents directly by national program scientists, with introduction of the clones to CIAT for recombination.

Generally, a given clone is evaluated through the preliminary yield trial phase of selection before being included in hybridization blocks. Thus, hybridizations are made almost exclusively among clones having proven characteristics. As nearly all agronomically important traits in cassava demonstrate high additive genetic variance, the *per se* performance of a clone is usually closely related to its value as a parent.

Combining ability as measured by progeny performance is estimated in segregating populations, based on overall family evaluations in a

given edaphoclimatic zone. This system has now been used at CIAT for three years and has also been adopted in Mexico and Brazil. It provides rapid feedback on the strengths and weaknesses of particular parental clones, and necessary adjustments are then made in the composition of hybridization blocks in the following cycle.

Recombination is accomplished both by controlled pollinations and by open pollination in polycross blocks. During 1984, out of a total of 176,427 seeds produced, 22,798 were by controlled pollination and 153,629 by open pollination. Most recombinations are made among clones of the same edaphoclimatic zone (ECZ) adaptation; however there is also considerable genetic interchange among clones adapted in any of the three lowland tropical zones.

At present, four populations are being developed, corresponding to materials adapted in ECZs I, II, V and VI (see Table 2). Selection of parents for ECZ III has only recently begun, and hybridization for this zone has not yet been initiated. As ECZ IV is of limited importance, no population is specifically developed for this zone. Rather, populations for other zones are evaluated at CIAT-Palmira serving as source material for ECZ IV.

Hybrid Selection

Selection methodology based on decentralization of evaluations has been detailed in previous Cassava Annual Reports (1982, 1983). The following sections relate goals and progress for each edaphoclimatic zone. For all populations, CIAT seeks general adaptation to the given soil and climatic conditions, resistance to prevalent diseases and pests, good root quality (especially, high dry matter content), high yield potential and efficient plant types. Furthermore, each population has other specific objectives, which are described below.

CIAT has dual objectives in germplasm development. First, segregating populations are produced for those programs with the capability of managing seeds. Secondly, clones are selected which can have direct potential as new varieties, or as parental material for use by national programs.

(ECZ I): lowland tropics; low to moderate rainfall; long dry season

Selection criteria. ECZ I is given the highest priority for breeding. An estimated 40% of the world's cassava is grown under these generalized conditions. Special problems of this zone are drought stress during the long dry season, and heavy insect and mite infestations. Diseases may be regionally important within the zone, but are less severe than in ECZ II. Low water and high temperature stress after planting may result in poor germination. Poorly adapted clones suffer marked decrease in root dry matter content over the dry season, and even more at the onset of the rainy season. These problems define the major zone-specific selection criteria.

Breeding strategy. The principal selection site for ECZ I is Media Luna, Magdalena, on the Atlantic coast (Table 5; Figure 1). All stages of selection, from segregating populations to advanced yield trials, are carried out at this site. The secondary selection site shifted this

year from Valledupar, Cesar, to the ICA station at Carmen de Bolivar, Bolivar. The latter appears to be more representative of a larger area of ECZ 1. Clones enter the Carmen de Bolivar site after passing the single row trial in Media Luna.

Germination ability. The Media Luna environment usually places some stress upon the plants during germination, and non-adapted clones germinate poorly. This year's first semester plantings were exposed to particularly high stress, probably a combination of high temperatures, a short dry period, and possibly Diplodia infection. Germination in the advanced yield trial ranged from 9 to 95% (Table 6). All clones were planted with stakes taken from Media Luna trials. In the analysis of variance, variety effects were highly significant (1%), indicating the possibility of selecting for good germination ability in this zone.

In another trial planted at the same date and location, germination and early vigor were compared for CIAT vs. Media Luna stakes for three varieties (Table 7). Nearly all CIAT stakes germinated for all three varieties, while Media Luna stakes germinated well only for M Col 22, a regional variety. Early vigor, based on a subjective evaluation, was also lower for the plants from the Media Luna stakes for the varieties M Col 1684 and M Ven 25. These data highlight the importance of production of planting material within the region of interest to select for good germination ability. Further studies are needed to determine more efficient methods of selecting for this character, as well as the mechanisms involved.

Drought tolerance. Mechanisms of drought tolerance in cassava are becoming better understood (see Physiology Section of this report). Nevertheless, the most effective selection technique at present still seems to be selection for yield and quality under representative drought stress conditions. In the second semester planting in Media Luna in 1983, the post-planting rainfall was unusually low (Oct. 21 plantings; see Figure 1). After only one month of significant rainfall, this planting was exposed to six months of drought (total of 146 mm during the period) on light, sandy soils. The level of drought stress was so severe that many plants died. Five apparently drought-susceptible clones suffered over 50% post-germination mortality (Table 8). In contrast, 15 clones had over 95% survival and a maximum yield of 20 tons/ha of fresh roots was obtained. No obvious patterns emerge in terms of gross morphological traits or parentage that would indicate an improved selection methodology.

Advanced yield trials. Advanced yield trials of ECZ I selections were harvested in the first semester in Urumitas, the Guajira, and in both first and second semesters in Media Luna (Tables 9, 10 and 11). In all trials, yields of selected hybrids and accessions were well above those of local varieties. In the Guajira, due to a combination of a long dry season and heavy mite attacks, overall yields and root dry matter contents were low. The local variety, Enanita, which is normally irrigated during the dry season in this region, had a fresh yield of only 2 t/ha, while several hybrids yielded over 10 t/ha. Virtually all the highest yielding hybrids have M Col 22 in their geneology.

Under this level of water stress (see Figure 1) it appears difficult to produce roots of good quality for fresh consumption, as most are low in dry matter content and high in cyanide content (HCN). M Col 2215 (Venezolana) maintained a remarkably high dry matter content (34%) for these conditions, in spite of its susceptibility to mites. There is now a good level of mite resistance in many of the clones adapted to ECZ I conditions.

In the first semester planting at Media Luna, fresh root yields of best clones exceeded 20 t/ha, about double the yields of the local varieties, Secundina and Venezolana. Further breeding is needed to continue to improve plant architecture and the plants' ability to maintain high dry matter over the long dry season.

The second semester (late rainy season) planting in Media Luna suffered extended drought soon after germination, resulting in plant mortality among susceptible clones, as discussed above. In spite of this severe stress, yields of 20 t/ha fresh yield and 5 t/ha dry matter yield were obtained (Table 11). Dry matter contents were low for all clones. Because of the minimal plant development prior to the onset of the rainy season in late April, much of the photosynthetic energy was directed toward top growth rather than root bulking. Although late rainy season plantings of cassava are not common, the increasing industrialization of cassava roots requires production throughout the year, which can be achieved in part by staggered plantings. In areas with an extended dry season, it is likely that different varieties will be required for optimum adaptation to the two planting seasons.

Yield trends in the ECZ I population. The 1981 Cassava Annual Report showed yield trends on the Caribia station from 1974-1980. In 1982, breeding trials were discontinued in Caribia and moved to Media Luna, as a higher stress site more representative of cassava growing regions within ECZ I. Trial mean yields dropped to about one half of what they were at Caribia (Figure 2). Though only one second semester yield trial has been harvested in Media Luna (the 1982-83B planting was destroyed by cattle) it appears that the late rainy season planting in Media Luna will not produce the dramatically better yields typical of the Caribia harvests in second semester, where soil water retention is higher and irrigation was occasionally applied. This expectation is also borne out by past experience with regional trials planted in Media Luna.

For ECZ I, high yielding check varieties are available, such as M Col 22, M Col 1468 and M Col 1684, though the latter two are of poor root quality. In most years, the mean yield of these checks has been higher than the trial mean, but best yielding clones (generally, new hybrids) have been well above the check yields (Figure 2). Without fertilizer, irrigation or pesticide applications, yields of about 20 t/ha are being achieved as an average of the top five yielders in each trial. Three years ago a massive increase in amount of germplasm being evaluated in this zone was begun, and this new emphasis is now showing up as higher yields in the earlier phases of selection.

(ECZ II): lowland tropics; moderate to high rainfall; savanna vegetation on acid soils

Breeding strategy. ECZ II represents areas of high future potential for cassava relative to other crops less tolerant of low fertility and acid soil conditions. Major problems for cassava production in this zone are a complex of diseases during the rainy season (bacterial blight, superelongation disease, anthracnose), a complex of mites and insects during the long dry season (green cassava mite, lacebug, thrips and mealybug), water deficits, low native soil fertility and soil acidity. This array of difficult constraints can be managed largely through varietal resistance/adaptation. Nevertheless, within the germplasm collection, only a very narrow range of materials have reasonable combined resistance to the major yield-limiting factors. Through recurrent selection in a population developed specifically for those conditions, CIAT has developed a broad base of improved clones. Principal remaining challenges are to combine good resistance to the wet season disease complex, with resistance to the dry season pest complex, and to further improve yield potential.

The definition of breeding priorities for this zone is complicated by the fact that Carimagua represents an ecosystem where cassava is a recent crop, and the level and balance of pests and diseases are constantly changing in unpredictable ways. The only assurance of achieving adequate resistance is to evaluate new clones over several years of changing pest and disease pressures.

Yield trials. Over the past ten years, major emphasis has gone to combining superelongation and bacterial blight resistance with good yield potential and high root quality. Progressive improvements have led to a broad-based population which performs considerably better than local checks (Tables 12 and 13). The continued high potential of disease pressure, especially superelongation, is illustrated by the fact that the susceptible checks are devastated by disease. M Ven 77 continues to be a standard for disease resistance, and intermediate and relatively stable yields. Nevertheless, many hybrids now have disease resistance levels similar to M Ven 77, with considerably higher yield potential.

Second semester plantings in Carimagua tend to escape the most severe disease pressure. In the past, a late planting strategy functioned to keep yields at reasonable levels. However, in the recent years, several mite and insect species have continued to build up during the dry season, and yields in some years have been lower for the second semester planting as compared to the first (Figure 3).

During the 1983-84B plantings, Vatiga lacebug attack was especially severe, with complete defoliation of susceptible clones. Two of the best clones for disease resistance and yield potential (CM 523-7 and M Ven 77) proved to be highly susceptible to Vatiga. Lacebug damage, in turn, appeared to facilitate infection by the superelongation pathogen, as normally resistant clones showed high susceptibility after Vatiga attack. Good levels of Vatiga resistance combined with bacterial blight and superelongation resistance are available in only a limited number of

advanced lines (Table 13), and priority is being given to further improving that resistance.

As there is such a wide range of breeding objectives which must be considered for this zone, CIAT has stratified objectives based on the planting season: for early rainy season plantings, more emphasis is given to the disease complex, while for late season plantings, mites, insects and drought are more important.

Yield trends in the ECZ II population. Selection for Carimagua conditions has now been carried out over a 10 year period. An analysis of progress was given in the 1981 Cassava Annual Report. In the present report, Figure 3 shows the yields since 1980-81A, for the mean of advanced yield trials, mean of the five top-yielding clones, and mean of three check varieties (Llanera-local variety, M Col 1468 and M Ven 77). Regression equations were calculated to determine rates of change in yields over seasons and years (Table 14). Trial mean yields as well as yields of the top five clones have increased at an average rate of 1.7 t/ha/year of fresh roots, while the top-yielding clones maintain approximately double the yield of the trial mean. At the same time, check yields declined at a rate of about 0.8 t/ha/year.

Separating the A and B seasons provides more insight into the dynamics of these yield changes. Trial mean yields for the A (wet) season increased at a rate of 3.0 t/ha/year, while check yields remained unchanged. For the B (dry) season plantings, yields increased only slightly, while check yields declined at a rate of about 1.1 t/ha/year. These trends may indicate that disease pressures during early season plantings are stabilizing, while the dry season pest complex is increasing in severity.

Despite static yields during B season plantings, genetic progress is indicated by comparison with check varieties. More recently, emphasis is being given to incorporating mite and insect resistance into this population, and actual yields should begin to increase at a higher rate, as appears to be the trend in the latest B season harvest. The steady overall progress in Carimagua can be attributed to a long term priority given to this region and an environment favorable for selecting for pest and disease resistance. Similar levels of progress can be expected at least into the medium range future.

(ECZ III): lowland tropics; high rainfall; humid rainforest vegetation

CIAT has previously had only a limited number of regional trials in this zone, though always recognizing its importance for cassava production. As the number of problems requiring resolution through breeding appeared to be fewer than in other edaphoclimatic zones, it was believed that clones selected in other lowland tropical zones would have a good possibility for acceptable performance in the lowland humid tropics. To test this hypothesis and to gain more precise information on problems of cassava in the zone, in 1984 CIAT began large scale germplasm screening, plus an evaluation of selected clones with diverse adaptation and resistance characteristics, near Florencia, Caqueta. This region has high rainfall (about 4,000 mm/year) and acid soils of

low fertility. Preliminary, pre-harvest observations suggest that ECZ II-selected clones may have the best chance of good performance in ECZ III.

(ECZ 4): medium altitude tropics

Breeding strategy. As the middle altitude tropics are of relatively low priority for cassava improvement, no breeding population is developed specifically for this zone. However, as CIAT's headquarter's station is located within ECZ 4, and all materials from all breeding populations are maintained and evaluated here, an opportunistic selection is practiced for any material with good performance at CIAT. Thrips and mite populations are generally high at CIAT during some period of the year, so this station also serves as a site for evaluation of selections from all other zones.

Advanced yield trials. The CIAT-Palmira station is generally regarded to be a high productivity site. However, during the 1983-84A planting, trials suffered a combination of severe drought stress (Figure 1), and thrips and mite attack, resulting in overall yields among the lowest for any site in Colombia during the year (Table 15). Thrips and mite susceptible clones were almost uniformly low yielding. Newer hybrids having both pest resistance and higher yield potential far outyielded the local cultivar Valluna. Many hybrids now have resistance levels to withstand even the most severe attacks with only minimal damage.

The second semester planting received much more favorable rainfall, and consequently less attack by thrips and mites. Yields of best clones exceeded 50 t/ha of fresh roots (Table 16).

(ECZ V): highland tropics

Breeding strategy. Varietal adaptation of cassava to low temperatures is completely distinct from that of the lowland tropics. Consequently, a separate gene pool is being developed for the highlands. The germplasm base of accessions adapted to the highlands is very limited. Part of the breeding strategy for this zone is to broaden this base by gradually incorporating genes for high yield potential from non-adapted clones. The major thrust, however, continues to be crossing among adapted clones to exploit additive genetic variability. Apart from low temperatures, another major constraint in the highlands is *Phoma* leaf spot, which is especially severe during high rainfall periods.

F_1 crosses among selected parents are planted in CIAT-Palmira for production of vegetative planting material, which is then taken to Popayan (1800 msl) with no prior selection. All stages of selection are thereafter carried out in Popayan. (The growing cycle in Popayan of 18 months tends to limit the rate of progress in this zone).

Advanced yield trials. The breeding program for the highlands is relatively new, and the first hybrids are just coming through the pipeline to the advanced yield trial stage of evaluation. The 1982B-1984A yield trial included hybrids from crosses designed to recombine traits from adapted by moderately adapted clones to broaden

the genetic base of the population. Several hybrids yielded as well as, or slightly better than, the local variety, Popayan (Table 17). These clones are being backcrossed to the highland adapted clones to improve adaptation and yield. This infusion of exotic germplasm should increase genetic variability within the highland population and facilitate genetic gains in the future.

(ECZ VI): subtropics

As no part of Colombia extends to the subtropics, CIAT cannot select directly for these conditions of fluctuating photoperiod and low winter temperatures. Over the past several years CIAT has made crosses among selections made by national programs working within the subtropics, and distributed seed to these and other breeding programs. During 1983 and 1984, several hundred germplasm accessions and hybrids were shipped *in vitro* to Cuba to begin a collaborative program of germplasm evaluation in the subtropics. These clones are presently under multiplication.

Special Studies

Early generation selection for root dry matter

Root dry matter content is a highly heritable characteristic, and the possibility of effective selection among F_1 individual plants has been shown (Cassava Annual Report, 1980). Normally, however, the techniques used to estimate dry matter content are too slow for practical use in selection of individual plants. It is precisely at this stage, though, where a rapid technique would be most useful to eliminate unacceptably low dry matter genotypes, and thereby streamline the selection process.

A simple select/reject evaluation procedure was developed based on the relation between root specific gravity and dry matter content. A salt (NaCl) solution was prepared with 150g NaCl/l solution. At the F_1 harvest in CIAT-Palmira in 1983A, a section of root of about 5 cm length was cut from the center of a single, intermediate-sized root of each plant, and the peel removed. The sample was placed in a wire mesh screen and submerged in the salt solution (about 6/l solution in a 10/l bucket). If the sample sank, it was assigned a score of 1, and if it floated, a score of 0.

Plants were propagated vegetatively and two separate sets of clones planted in a single row trial, one set in both CIAT and Media Luna, and the other set in both Carimagua and CIAT. At the harvest of the single row trials, root dry matter was estimated by the root specific gravity method using a series of salt solutions (Cassava Annual Report, 1979).

Correlations between individual F_1 plants at CIAT-Palmira and the single row trials in the three sites were: CIAT-Palmira: $r = 0.31^{**}$ ($n = 1019$); Media Luna: $r = 0.12$ ($n = 70$); Carimagua: $r = 0.24^{**}$ ($n = 96$). In spite of being highly significant for two sites, these levels of correlation may be too low to be useful in a breeding program.

Effects of drought and mite attack on yield and quality

In many regions of ECZ I, the dry season drought stress and mite

attacks combine to reduce yield and root quality. The contributions of each factor and their interactions have not been well-documented. For a practical breeding program the breeder should have this information to assign priority in selection.

A trial to study these effects was planted in Urumitas, the Guajira, in a semi-arid zone of northeastern Colombia. The trial consisted of a factorial design with three clones (M Col 1684, M Ven 25 and CM 681-2), insecticide protected vs. unprotected, irrigated vs. unirrigated, and four harvest dates (21, 29, 37 and 43 weeks after planting). Only one irrigated and one unirrigated replication each were used due to management constraints, so no statistical analysis was possible for this comparison. Nevertheless, the land for the experiment was relatively uniform, and comparisons should be valid. Figures 4 and 5 illustrate changes over time for root dry matter yield and the percentage of root dry matter for each variety, and for each of the four protected and irrigated treatment combinations.

With neither irrigation nor protection, maximum yield was reached already at the 29-week harvest. There were significant differences among clones, but all responded similarly across harvest dates. With either protection or irrigation, yields continued to increase linearly up to final harvest. For M Ven 25 and M Col 1684, either protection or irrigation produced about the same effect, i.e., they are equally sensitive to yield loss to drought stress or to mite attack under the experimental conditions. On the other hand, CM 681-2 achieved a yield curve without protection which was nearly indentical to that with both irrigation and protection. This clone appears to be tolerant of mite attack when provided with adequate water, but less tolerant under a water deficit condition.

When provided with both protection and irrigation, all clones continued to sharply increase yields over time, with a mean of about 0.4 t DM/ha/week. CM 681-2 maintained a strong yield advantage over the other two clones under all treatment combinations, illustrating the feasibility of selecting individual cassava varieties for adaptation to a range of water deficit and mite attack levels.

Root dry matter content declined after either the 2nd or 3rd harvest for all treatment combinations except under both irrigation and protection (Figure 5). Under irrigation, dry matter content on the average was similar with or without protection up to the third harvest, after which it declined without protection, and increased under protection. M Ven 25 and CM 681-2 had similar response curves across all treatments, while M Col 1684 had an overall lower dry matter content, and was more sensitive to stress. Overall, water stress effects caused a higher reduction in root dry matter than did mite damage.

Conclusions from the experiment relative to breeding strategy are that: (1) selection of individual clones with superior performance over a range of water deficit and mite damage levels is feasible; (2) as interaction between effects of water stress and mite attack stress was small, significant progress can be made in breeding even when tolerance to these two characters is selected for separately within the same

population. An example could be selection for mite resistance in CIAT-Palmira (where drought stress is unusual), and for drought tolerance in Media Luna (where mite attacks are only low to moderate). (3) Under conditions of extended drought, early root bulking as an escape mechanism appears to be highly effective. CM 681-2 had over twice the yield of either M Ven 25 or M Col 1684 at the 21-week harvest for all treatment combinations. Even for those treatment combinations where bulking rate was similar among clones for the remainder of the cycle, CM 681-2 maintained a yield advantage due to its early bulking.

Regional Trials

The regional trial network in Colombia, a collaborative effort between CIAT and ICA, serves a dual purpose. First, the trials are a continuation of the germplasm development process following the advanced yield trial stage. As such, the trials include germplasm selected for a broad range of national program needs. Secondly, the trials directly serve the interests of the Instituto Colombiano Agropecuario ICA to select clones specifically suited to Colombian conditions.

The regional trials focus on germplasm, where agronomic practices are held constant within a given trial. A minimum input philosophy is employed, where no irrigation or pesticide protection is used, and low levels of fertilizer applied only under conditions where soils are below critical levels for certain nutrients. Standard agronomic practices include good land preparation, adequate weeding, stake treatment, and appropriate plant density.

The selection of planting sites is based not on achieving the highest possible yields but rather sites representative of edaphoclimatic, and pest and disease conditions where cassava is actually widely grown, or has a high future potential. These sites tend to be within more marginal areas for crop production (Figure 6).

Germplasm which enters regional trials is selected on the basis of performance in advanced yield trials (over at least two years) or in a previous regional trial. Trials are not uniform; only adapted germplasm is included for trials in a given region. Across sites with similar edaphoclimatic conditions, trials have a similar but not necesssarily identical set of clones. The materials included in the 1983/84 regional trials in 13 sites are given in Table 18, and the following sections summarize the results. Although data are taken throughout the season on a wide range of characters, only yield data are presented here.

Edaphoclimatic zone I

A nearly uniform set of clones was included in the six sites in the Atlantic Coast region. Mean yields ranged from 2.2 to 6.9 t/ha DM while the maximum yield obtained was 10.2 t/ha for M Ven 25 at Pivijay. The local variety, Venezolana, known throughout the region for its high and stable yields and good root quality was among the better performing clones. Nevertheless, in all sites, introduced clones exceeded the yield of Venezolana. Broad adaptability of several clones across ECZ I conditions is demonstrated by their ability to yield above the trial mean in most or all sites. M Col 22, M Col 1505, M Ven 25 and CM 681-2,

by this measure, are the most widely adapted within ECZ I, with M Col 1684 and Venezolana also being acceptable.

M Col 1505, also known locally as "Green Bud Venezolana", was originally introduced into the area through the CIAT-ICA regional trials, and is now widely grown as a preferred variety. During 1984, it was officially released by ICA as Manihoica P-12.

Yields in Laberinto, Albania and Montanita were all highly correlated, while no clear relationship exists among other sites (Table 19). A single season's trials, however, are not sufficient to define the adequacy of testing sites.

Edaphoclimatic zone II

La Libertad, San Martin and Carimagua are sites within the acid soil, high rainfall savannas, with the first two in relatively more fertile soils at the edge of the Colombian llanos. Yields in both La Libertad and San Martin were high (7.5 and 7.4 t/ha DM, respectively), while Carimagua yields suffered both from lower soil fertility and higher disease and pest pressure. Yields at La Libertad, San Martin and early season (A) planting in Carimagua were all significantly correlated. Yields in the late season (B) planting were not correlated with those at any other site. However, the number of clones common across sites (with the exception of La Libertad and San Martin) was low, so no broad conclusions can be drawn. The hybrids CM 507-37, CM 523-7 and CM 723-3 excelled in this zone, with yields well above the local variety, LLanera.

Edaphoclimatic Zone IV

CIAT-Palmira and Quilichao are both situated in the medium altitude tropics, at about 1000 msl. While CIAT soils are considerably more fertile than those at Quilichao, mean yields this year at Quilichao were over double those at CIAT due to a severe drought there, accompanied by heavy thrips and mite attack (Table 18). Nevertheless, the correlation for yield between the two sites was highly significant, showing the principal yield-influencing factors to be similar. CM 849-1, which has in the past given consistently high yields in ECZ IV, was in first place in yield in both sites. Other outstanding clones across both sites were CM 489-1, CM 955-2 and CM 962-4. M Col 1468, while a popular variety in the Valle and Cauca departments, was among the lowest yielding at both CIAT and Quilichao due to thrips and mite attacks. The higher levels of resistance of newer hybrids confers a large yield advantage under heavy pest pressure.

Edaphoclimatic Zone V

ECZ V was represented by Mondomito, which could be considered as bordering between zones IV and V. As hybrid selections for this zone have not yet advanced to the regional trials, a large proportion of local varieties were included in this trial. Among introduced clones, M Col 2019 excelled at 9.4 t/ha DM and CM 507-37 yielded equal to the trial mean, 6.2 t/ha. Yields at Mondomito were not correlated with those at any other site. Future trials here should include only highland-adapted clones.

Table 1. Origin of accessions in CIAT's cassava germplasm collection.

Country of origin	Number of accessions
Argentina	16
Bolivia	3
Brazil	818
Colombia	1596
Costa Rica	131
Cuba	74
Dominican Republic	5
Ecuador	118
Guatemala	90
Malaysia	3
Mexico	64
Panama	39
Paraguay	102
Peru	247
Philippines	2
Puerto Rico	15
Thailand	1
Venezuela	242
CIAT hybrids	114
TOTAL	3680

Table 2. Edafoclimatic zones for cassava production and their main characteristics.

Edafoclimatic zone (ECZ) no.	General description	Sites in Colombia for germplasm evaluation and breeding.	Major yield constraints
1	Lowland tropics with long dry season, low to moderate annual rainfall, high year-round temperature.	Media Luna, Carmen de Bolivar	Drought, mites, thrips, mealybugs, termites, bacteriosis, root rots, viruses.
2	Acid soil savannas with moderate to long dry season, low relative humidity during dry season.	Carimagua	Low soil fertility, drought, bacteriosis, superelongation, anthracnose, Cercospora leafspot, mites, mealybugs, lace bugs.
3	Lowland tropics with no pronounced dry season, high rainfall, constant high relative humidity.	Florencia	Low soil fertility, superelongation, Cercospora leaf spot, root rots.
4	Medium-altitude (800-1500 msl) tropics with moderate dry season and temperature.	CIAT-Palmira,	Thrips, mites, mealybugs, bacteriosis, mycoplasma, anthracnose, root rots, and viruses.
5	Cool, tropical highland (1600-2200 msl) area with mean temperatures of approx. 17-20°C.	Popayan	Low temperature, Phoma leafspot, anthracnose, mites.
6	Subtropical areas, with cool winters and fluctuating day-lengths.	None	Low winter temperature, bacteriosis, superelongation, anthracnose.

Table 3. Preliminary evaluations of 240 recent Brazilian introductions for disease resistance in Carimagua, 1982A and 1984A; including M Bra 67 - M Bra 311, from CNPMF, Cruz das Almas, Brazil.

Disease damage rating[a]	Frequency of clones (%)	
	Bacteriosis	Superelongation
1	0.0	0.0
2	0.0	4.2
3	5.4	20.0
4	57.9	31.2
5	36.7	44.6

[a] 1 = low damage; 5 = high damage.

Table 4. Accessions combining moderate to high levels of resistance to bacterial blight (CBB) and superelongation disease (SE) among 240 recent introductions from CNPMF, Cruz das Almas, BA, Brazil. Evaluations from Carimagua, 1982A and 1984A.

CIAT code	CENARGEN code	Common name	Disease rating[a]	
			CBB	SE
M Bra 97	011053	Aipim Saracura II	3	2
M Bra 113	05037	Tupim branca	3	3
M Bra 136	008648	Mantiqueira	3	3
M Bra 169	005266	Variedade 24	3	2
M Bra 204	001406	IAC 14-16-7	3	3
M Bra 205	001503	Jamamd-3	3	3
M Bra 206	001554	Klainasik	3	3
M Bra 234	003719	Saracura III	3	2
M Bra 268	008281	Olho roxo II	3	2
M Bra 284	010570	Preita con folha muida	3	3

[a] 1 = low damage; 5 = high damage.

Table 5. Climatic and edaphic characteristics of selection sites for 1984 harvests of advanced yield trials.

Location	Altitude (msl)	Mean Temperature (°C)	Rainfall during cycle (mm) [a]	Soil characteristics				
				pH	Organic matter (%)	P (ppm)	K (me/100g)	Texture
Urumitas, Guajira	200	28.0	A: 926	8.1	1.3	142.0	0.51	Clay loam
Media Luna, Magdalena	10	27.2	A: 1058 ; B: 679	6.3	0.7	6.0	0.06	Sandy loam
Carimagua, Meta	200	26.2	A: 2582; B: 2269	4.5	3.5	4.0	0.14	Clay loam
CIAT-Palmira, Valle	1000	23.8	A: 571; B: 932	7.1	4.0	58.0	0.64	Clay
Popayan, Cauca	1750	18.0	A: 3298	4.7	28.7	3.4	0.24	Loam

[a] Actual rainfall during cycle for A (early planting) and B (late planting) season.

Table 6. Comparison among cassava clones for germination ability under high temperature and drought stress conditions. Data from replicated yield trial (75 plants per clone), Media Luna, Magdalena, 1984-85A.

≥% germination	≤30% germination	Checks	
		Clone	Germination (%)[a]
M Bra 35	M Bra 89	M Bra 12	85
M Bra 71	M Bra 135	M Col 22	60
M Bra 73	M Col 2147	M Col 1468	71
M Bra 106	M Col 2210	M Col 1684	59
M Bra 125	M Col 2212	M Ven 77	45
M Cub 49	M Cub 64	Secundina	88
M Per 283	M Ven 23	Venezolana	95
M Ven 185	CM 1960-11		
CG 1-56	CM 2086-6		
CG 3-3	CM 2086-7		
CG 7-66	CM 2086-16		

[a] LSD = 6.0

Table 7. Comparison among clones and between sources of planting material for germination and early vigor in an advanced yield trial in Media Luna, Magdalena.

Clone	Source of planting material	Germination (%)	Early vigor[a]
M Col 22	CIAT	99	3.0
	Media Luna	100	3.3
M Col 1684	CIAT	97	4.0
	Media Luna	65	3.0
M Ven 25	CIAT	99	4.3
	Media Luna	73	3.0

[a] Subjective evaluation where 1 = very low vigor; 5 = very high vigor.

Table 8. Clones demonstrating contrasting drought tolerance as measured by post-germination survival in 1983-84B season planting of advanced yield trial in Media Luna, Magdalena.

Survival	Clone	Parents
95%	M Col 1828A	
	CM 342-170	M Col 22 x M Col 1468
	CM 696-1	SM 1-10 x M Col 1684
	CM 976-15	CM 321-160 x M Col 1684
	CM 1015-34	M Col 22 x M Col 1684
	CM 1016-12	M Col 22 x M Mex 11
	CM 1016-30	M Col 22 x M Mex 11
	CM 1016-34	M Col 22 x M Mex 11
	CM 1286-7	CM 409-2 x CM 477-3
	CM 1322-2	CM 454-1 x CM 180-4
	CM 1785-6	CM 507-13 x CM 326-407
	CM 1797-4	CM 516-7 x CM 326-407
	CM 1797-8	CM 516-7 x CM 326-407
	M Col 1468	
	M Col 1684	
50%	CM 982-20	CM 321-170 x M Col 1684
	CM 1203-11	CM 321-252 x CM 477-3
	CM 1334-5	CM 462-1 x M Col 1292
	CM 1350-7	CM 473-34 x CM 309-705
	M Ven 77	

Table 9 . Results of yield trial in Urumitas, Guajira, 1983-84A.

Clone	Parents	Fresh root yield (t/ha)	Root dry matter (%)	Dry root yield (t/ha)	Root HCN (1-9)[a]	Mononychellus mites (1-5)[b]	Thrips (1-5)[b]
CG 1-20	M Bra 12 x M Col 22	15	26	4	9	3.0	1.3
CG 5-16	M Col 22 x M Col 414	15	28	4	7	3.3	1.3
CG 1-7	M Bra 12 x M Col 22	14	26	4	8	3.0	1.0
CM 681-2	M Ven 185 x M Col 22	13	31	4	7	4.0	1.0
CG 1-57	M Bra 12 x M Col 22	12	24	3	9	3.0	1.3
CG 17-23	M Col 1434 x M Col 22	12	27	3	8	3.0	1.3
CM 1305-3	CM 446-22 x M Col 1684	12	25	3	9	3.3	1.0
CG 4-81	M Col 22 x M Col 282	12	28	3	7	3.3	1.0
CG 5-78	M Col 22 x M Col 414	11	26	3	7	2.3	1.3
M Tai 1		11	26	3	9	2.3	1.3
CG 1-17	M Bra 12 x M Col 22	10	29	3	7	2.3	1.0
CG 1-43	" "	10	25	3	8	2.7	1.0
M Ven 8		10	22	2	8	3.0	1.0
CG 7-30	M Col 113 x M Col 22	9	28	3	9	2.7	1.0
M Col 2215		9	34	3	7	5.0	1.0
Checks							
M Bra 12		2	24	1	9	2.7	1.0
M Col 22		10	28	3	7	4.3	1.0
M Col 1468		5	24	1	6	2.7	2.3
M Col 1684		5	22	1	9	2.3	3.3
M Ven 77		2	21	1	8	2.7	1.0
Enanita (local)		2	30	1	5	2.5	1.0
Mean (49 clones;	checks excluded)	8	26	2	8	3.1	1.2
LSD (5%)		5.5	5.0	1.5			

[a] 1 = very low (< 20 ppm CN^-); 9 = very high (> 150 ppm CN^-)

[b] 1 = very low damage; 5 = very high damage

Table 10 . Results of yield trial in Media Luna, Magdalena, 1983-84A.

Clone	Parents	Fresh root yield (t/ha)	Root dry matter (%)	Dry root yield (t/ha)	Root HCN (1-9)[a]	CBB (1-5)[b]
CM 1533-9	CM 309-163 x M Col 1684	29	28	8	8	3.0
M Mal 2		22	NA	NA	NA	3.0
CM 962-4	CM 309-93 x M Pan 70	20	31	6	5	3.0
CM 1022-4	M Col 22 x CM 416-2	20	30	6	7	3.7
M Mal 3		20	29	6	7	3.0
M Ven 23		19	37	7	9	3.0
M Ven 8		19	26	5	8	2.5
M Tai 1		18	28	5	9	3.3
CM 1223-11	CM 323-125 x M Col 1684	18	32	6	9	2.5
M Ven 157		17	30	5	8	3.0
M Col 1823		17	33	6	8	3.0
CM 976-15	CM 321-160 x M Col 1684	17	36	6	9	4.0
CM 847-11	SM 76-66 x M Col 1684	17	32	5	9	2.0
M Ven 25		17	35	6	9	2.5
CM 955-2	CM 309-37 x M Ven 218	16	31	5	7	3.7
Checks						
M Bra 12		15	29	4	8	3.0
M Col 22		10	31	3	8	3.0
M Col 1468		14	29	4	8	2.0
M Col 1684		12	29	4	9	2.5
M Ven 77		12	28	3	8	2.0
Venezolana (local)		11	37	4	5	3.3
Secundina (local)		15	33	5	6	3.5
Mean (39 clones; checks excluded)		13	31	4	7	3.3
LSD (5%)		5.2	2.8	1.7		

[a] 1 = very low ($<$20 ppm CN^-); 9 = very high ($>$150 ppm CN^-)

[b] 1 = very low damage; 5 = very high damage

Table 11. Results of yield trial in Media Luna, Magdalena, 1983-84B.

Clone	Parents	Fresh root yield (t/ha)	Root dry matter (%)	Dry root yield (t/ha)	Root HCN (1-9) [a]	*Cercospora vicosae* (1-5) [b]	CBB (1-5) [b]
CM 696-1	SM 1-10 x M Col 1684	20	25	5	8	1.7	2.0
CM 1797-4	CM 516-7 x CM 326-407	20	27	5	6	2.0	2.7
CM 1286-7	CM 409-2 x CM 477-3	17	23	4	8	4.0	2.3
CM 1015-34	M Col 22 x M Col 1684	16	29	5	8	2.0	1.7
CM 1785-6	CM 507-13 x CM 326-407	14	29	4	8	1.3	2.3
CM 1015-42	M Col 22 x M Col 1684	14	28	4	9	2.0	2.3
CM 1362-10	CM 477-3 x M Col 1684	13	23	3	6	2.0	2.3
CM 342-170	M Col 22 x M Col 1468	12	27	3	8	3.3	2.0
CM 1305-3	CM 446-22 x M Col 1684	12	23	3	8	1.3	2.0
CM 1797-8	CM 516-7 x CM 326-407	12	30	4	7	2.7	2.7
CM 1297-9	CM 442-5 x M Col 1684	11	26	3	7	2.0	2.0
CM 1015-16	M Col 22 x M Col 1684	11	28	3	8	2.0	2.0
CM 1278-7	CM 409-2 x M Col 1684	11	27	3	9	2.3	2.3
CM 1016-34	M Col 22 x M Mex 11	11	29	3	9	3.0	2.3
CM 1016-30	"	11	30	3	8	4.0	2.0
Checks							
M Bra 12		5	25	1	8	2.0	2.0
M Col 22		9	28	2	8	2.7	2.3
M Col 1468		13	25	3	6	3.0	2.0
M Col 1684		15	28	4	9	1.7	2.0
M Ven 77		2	23	<1	4	2.5	2.0
Secundina (local)		4	29	1	5	3.7	2.7
Mean (45 clones; checks excluded)		8	28	2	7	2.6	2.2
LSD (%)		4.2	3.2	1.2			

[a] 1 = very low (<20 ppm CN-); 9 = very high (>150 ppm CN-)

[b] 1 = very low damage; 5 = very high damage

Table 12. Results of yield trial in Carimagua, Meta, 1983-84A.

Clone	Parents	Fresh root yield (t/ha)	Root dry matter (%)	Dry root yield (t/ha)	Root HCN (1-9)[a]	CBB (1-5)[b]	Super-elongation (1-5)[b]	*Vatiga* lacebug (1-5)[b]
SG 104-283		27	34	9	9	3.0	2.7	3.0
SG 104-264		24	31	7	7	3.0	1.7	3.3
SG 107-35		23	31	7	6	2.3	3.0	3.0
CG 32-22	M Bra 20 x M Pan 97	22	33	7	6	3.3	3.0	3.3
SG 104-284		21	28	6	5	2.7	1.7	3.7
CM 2088-1	CM 727-14 x CM 517-1	21	34	7	3	3.0	2.3	2.7
CM 723-3	CM 180-4 x M Col 647	21	32	7	5	2.0	1.0	3.0
SG 104-74		21	32	7	6	3.0	2.0	3.0
SG 104-164		20	32	7	8	2.7	1.3	3.0
SG 107-47		20	33	7	3	3.0	3.0	3.0
CG 32-9	M Bra 20 x M Pan 97	20	29	6	4	3.0	2.7	3.7
CG 26-12	M Bra 20 x M Col 1468	19	32	6	6	2.7	1.3	3.0
CG 144-1	M Col 1468 x M Pan 128	19	29	6	4	3.0	2.3	3.3
SG 104-13		19	36	7	7	3.0	2.0	2.3
CG 106-1	M Col 701 x M Bra 21	18	28	5	6	3.0	2.3	3.7
Checks								
M Bra 12		0		0		3.0	5.0	3.0
M Col 22		1		1		3.7	4.0	3.3
M Col 1468		8	26	2	3	3.0	4.0	4.0
M Col 1684		10	30	3	9	3.0	3.0	3.0
M Ven 77		15	29	4	6	2.7	2.3	3.0
Llanera (local)		7	30	2	2	2.3	3.5	3.3
Mean (53 clones; checks excluded)		15	32	5	6	3.0	2.5	3.3
LSD (5%)		6.1	3.1	2.1				

[a] 1 = very low ($<$20 ppm CN^-); 9 = very high ($>$150 ppm CN^-)

[b] 1 = very low damage; 5 = very high damage

Table 13. Results of yield trial in Carimagua, Meta, 1983-84B.

Clone	Parents	Fresh root yield (t/ha)	Root dry matter (%)	Dry root yield (t/ha)	Root HCN (1-9)[a]	Vatiga Lacebug (1-5)[b]	CBB (1-5)[b]	Super-elongation (1-5)[b]
CM 2306-7	CM 516-7 x CM 841-58	32	33	11	8	3.5	2.7	2.5
CM 2298-3	CM 516-7 x M Bra 5	30	36	11	4	2.5	3.0	3.0
CM 2452-5	CM 727-14 x CM 834-16	27	35	10	4	3.2	2.2	2.0
CM 2166-6	CM 430-37 x M Ven 218	26	35	9	3	3.5	2.7	2.0
CM 2177-2	CM 430-37 x CM 840-138	26	35	9	3	2.8	2.5	3.0
CM 2087-101	CM 727-14 x CM 459-5	25	33	8	6	3.0	3.0	3.3
CM 2398-1	CM 630-133 x CM 517-2	25	32	8	4	3.0	3.0	3.2
CG 388-2	M Col 1237 x M Bra 12	24	37	9	6	3.0	3.2	2.8
CM 854-21	M Mex 17 x M Col 638	23	35	8	3	2.8	3.0	1.8
CM 2118-2	M Col 638 x CM 523-7	23	34	8	4	3.5	3.0	3.7
CM 1794-204	CM 516-7 x M Col 638	22	34	8	4	3.0	2.5	3.2
CM 723-3	CM 180-4 x M Col 647	22	35	8	5	3.3	2.0	1.7
CM 2177-1	CM 430-37 x CM 840-138	21	35	7	5	3.2	3.2	3.0
CM 2134-6	M Bra 12 x CM 516-6	21	35	7	8	3.5	3.0	2.7
CM 1335-4	CM 462-1 x M Col 1292	21	37	8	4	3.0	2.7	3.7
Checks								
M Bra 12		16	28	4	7	2.7	3.2	5.0
M Col 22		10	30	3	4	3.7	4.0	5.0
M Col 1468		7	30	2	5	3.8	3.5	4.0
M Col 1684		5	28	1	9	3.5	3.2	4.0
M Ven 77		12	29	3	5	3.5	3.0	2.3
Llanera (local)		7	32	2	4	3.5	2.8	3.8
Mean (30 clones; checks excluded):		20	34	7	5	3.2	2.9	3.2
LSD (5%)		6.2	2.4	2.1				

[a] 1 = very low ($<$20 ppm CN^-); 9 = very high ($>$150 ppm CN^-)

[b] 1 = very low damage; 5 = very high damage

Table 14. Yield trends in advanced yield trials in Carimagua since 1980.

Planting season	Slope and intercept in regression equation for:[a]		
	Trial mean yield	Mean yield of top 5 clones	Mean yield of checks[b]
Both seasons	0.87, 9.9	0.87, 19.1	-0.38, 11.8
A season	1.49, 6.6	1.61, 15.7	-0.03, 11.3
B season	0.08, 14.7	0.05, 23.6	-0.54, 11.8

[a] "Season" as X-axis, with 1980A as season 1, and 1983B as season 8.

[b] Checks: Llanera (local variety), M Col 1468, M Ven 77.

Table 15 . Results of yield trial in CIAT-Palmira, Valle, 1983-84A.

Clone	Parents	Fresh root yield (t/ha)	Root dry matter (%)	Dry root yield (t/ha)	Root HCN (1-9)[a]	*Mononychellus* mites (1-5)[b]	Thrips (1-5)[b]
CM 1014-2	M Col 22 x M Col 655A	23	36	8	6	2.0	1.3
CG 7-64	M Col 113 x M Col 22	22	35	8	5	2.3	3.0
CM 975-5	CM 321-160 x M Col 1292	22	36	8	4	3.0	3.0
CG 6-18	M Col 22 x M Col 1438	22	38	8	2	2.3	2.3
CM 305-41	M Col 113 x M Col 22	22	33	7	4	2.0	2.0
CG 1-3	M Bra 12 x M Col 22	22	38	8	4	1.7	2.3
CM 996-6	CM 323-99 x M Col 638	21	30	6	4	3.0	2.0
CM 1491-5	M Ven 270 x M Mex 11	21	37	8	4	2.0	2.7
CM 1999-5	CM 516-15 x CM 517-1	21	34	7	5	3.0	3.0
CM 1690-2	CM 430-51 x M Ven 270	21	35	7	4	4.0	3.3
CM 1895-7	CM 430-51 x CM 459-5	20	33	6	3	2.0	3.0
CG 4-27	M Col 22 x M Col 282	19	34	6	5	2.0	2.3
CM 1335-4	CM 462-1 x M Col 1292	19	37	7	3	2.7	2.7
CM 1533-19	CM 309-163 x M Col 1684	18	32	6	7	4.0	3.0
CG 5-95	M Col 22 x M Col 414	18	34	6	5	1.7	2.3
Checks							
M Bra 12		19	35	7	3	1.0	2.0
M Col 22		7	33	2	5	3.0	2.7
M Col 1468		5	29	1	4	5.0	4.7
M Col 1684		5	24	1	9	4.0	5.0
M Ven 77		4	25	1	8	4.0	3.7
Valluna (local)		5	28	1	3	2.3	2.0
Mean (94 clones; checks excluded)		13	32	4	5	3.0	2.9
LSD (5%)		0.9	0.3	0.2			

[a] 1 = very low ($<$20 ppm CN^-); 9 = very high ($>$150 ppm CN^-)

[b] 1 = very low damage; 5 = very high damage

Table 16. Results of yield trial in CIAT-Palmira, Valle, 1983-84B.

Clone	Parents	Fresh root yield (t/ha)	Root dry matter (%)	Dry root yield (t/ha)	Root HCN (1-9)[a]	Thrips (1-5)[b]
CM 1983-101	CM 516-7 x CM 459-5	52	37	19	5	1.7
CM 2133-5	M Bra 12 x CM 507-34	51	36	18	6	1.0
CM 1305-3	CM 446-22 x M Col 1684	50	35	17	8	2.3
CM 2368-14	CM 630-9 x M Col 1468	50	36	18	4	3.0
CM 308-197	M Col 22 x M Col 361	50	40	20	2	1.0
CM 1307-3	CM 446-22 x CM 180-4	50	36	18	4	2.0
CM 2174-7	CM 430-37 x CM 523-7	49	38	19	2	2.0
CM 2136-2	M Bra 12 x CM 841-106	48	35	17	3	1.0
HMC 1		48	39	19	4	1.7
CM 1796-202	CM 516-7 x M Ven 270	46	38	17	4	3.0
CM 1203-13	CM 321-252 x CM 477-3	46	39	18	3	2.0
CM 489-1	M Col 882 x M Ven 270	46	36	17	3	3.0
CM 2174-1	CM 430-37 x CM 523-7	46	39	18	5	1.7
CM 2109-1	M Col 282 x M Col 1684	46	39	18	7	2.0
CM 2146-3	CM 180-5 x M Col 1468	45	39	18	4	2.7
Checks						
M Bra 12		30	35	11	2	1.0
M Col 22		28	40	11	3	1.3
M Col 1468		28	35	10	5	4.0
M Col 1684		28	31	9	8	3.3
M Ven 77		13	32	4	7	4.0
Valluna (local)		14	31	4	1	1.0
Mean (114 clones; checks excluded)		34	36	12	5	2.2
LSD (5%)		14.5	3.7	5.3		

[a] 1 = very low ($<$ 20 ppm CN^-); 9 = very high ($>$ 150 ppm CN^-)

[b] 1 = very low damage; 5 = very high damage

Table 17. Results of yield trial in Popayan, Cauca, 1982B-84A.

Clone	Parents	Fresh root yield (t/ha)	Root dry matter (%)	Dry root yield (t/ha)	Root HCN (1-9)[a]	*Phoma* leaf spot (1-5)[b]
CG 406-6	M Col 1522 x M Ecu 169	24	35	8	5	2.0
CG 401-6	M Col 1522 x M Col 340	19	32	6	3	2.5
CG 401-3	" "	19	31	6	5	3.0
CG 358-3	M Col 335 x M Col 2060	17	31	5	2	2.0
CG 403-18	M Col 1522 x M Col 1468	17	30	5	8	3.0
CG 406-4	M Col 1522 x M Ecu 169	17	26	4	4	2.5
M Ecu 33		16	31	5	5	3.0
CG 354-2	M Col 309 x M Col 1468	16	31	5	4	3.0
CG 406-5	M Col 1522 x M Ecu 169	16	33	5	5	3.0
CG 403-5	M Col 1522 x M Col 1468	16	29	5	5	2.5
CG 401-9	M Col 1522 x M Col 340	15	24	4	5	3.0
M Col 1927		15	30	5	3	3.5
CG 487-1	M Col 2061 x M Col 2060	15	27	4	4	3.0
CG 487-2	" "	15	29	4	4	2.5
CG 401-8	M Col 1522 x M Col 340	15	29	4	4	2.0
Checks						
M Col 22		1	-	1	-	4.0
M Col 1468		6	27	2	6	3.0
M Col 2059		9	26	2	2	2.5
M Col 2060		22	28	6	3	2.5
M Col 2061		12	29	3	4	3.0
Popayan (local)		18	31	5	2	2.0
Mean (27 clones; checks excluded):		14	29	4	4	2.7
LSD (5%)		6.1	3.8	2.1		

[a] 1 = very low ($<$20 ppm CN^-); 9 = very high ($>$150 ppm CN^-)

[b] 1 = very low damage; 5 = very high damage

Table 18a. Dry root yields for regional trials in Colombia; 1983-84. Trials in Edapho-climatic Zone I.

Clone	Laberinto, Sucre (A)[a]	Albania, Sucre (A)	Montañita, Sucre (A)	Carranzo, Cordoba (A)	Pivijay, Magdalena (A)	Sabanalarga, Atlantico (A)	Relative performance[b]
M Bra 12	3.2	5.0	3.4	5.8			0/4
M Col 22	4.5	6.1	4.3	6.4	5.5	3.9	5/6
M Col 1505	5.1	6.3	4.8	8.6	5.1	1.4	5/6
M Col 1684	4.7	9.0	5.5	6.2	7.8	1.3	4/6
M Ven 25	5.5	7.0	4.3	8.7	10.2	2.2	6/6
CM 507-37	2.8	4.4	3.2	5.5	5.5	1.0	1/6
CM 681-2	5.2	7.1	4.8	8.0	5.2	3.2	6/6
CM 922-2	3.7	6.5	2.5	8.6	1.4	3.2	3/6
CM 976-15	3.6	5.3	3.8	5.3	6.0	2.0	1/6
CM 981-8	1.7	3.8	2.0	5.4		2.2	1/5
Regional Varieties							
Secundina					2.1		0/1
Venezolana	5.3	6.8	5.4	7.8	4.5	2.1	4/6
Trial mean:	4.1	6.1	4.0	6.9	4.9	2.2	

[a] Town, department and planting season

[b] Proportion of sites in which yield equalled or exceeded trial mean, compared to total number of sites planted.

Table 18b. Dry root yields for regional trials in Colombia; 1983-84. Trials in Edapho-climatic Zones II, IV, and V.

Clone	La Libertad, Meta (A)[a]	San Martin, Meta (A)	Carimagua, Meta (A)	Carimagua, Meta (B)	CIAT-Palmira, Valle (A)	Quilichao, Cauca (A)	Mondomito, Cauca (A)	Relative Performance[b]
M Bra 5			4.3					1/1
M Col 1468	8.4	8.9	2.0	5.1	1.6	9.8	3.1	2/7
M Col 1495				3.6				0/1
M Col 1684	11.3	7.7		5.6	1.7	11.3		3/5
M Col 1895				4.1				0/1
M Col 1914				3.8				0/1
M Col 1916			2.9					1/1
M Col 2016							4.6	0/1
M Col 2019							9.4	1/1
M Pan 19				4.0				0/1
M Pan 90				2.9				0/1
M Pan 97				2.3				0/1
M Pan 101				3.6				0/1
M Per 245		8.7	2.4					1/2
M Ven 77			2.9	6.0		8.0	2.5	2/4
HMC 1					7.9			1/1
HMC 2	7.7	5.3			0.4		3.5	1/4
CM 91-3	3.2	6.4	1.0		6.4	11.7		1/5
CM 305-41					9.9			1/1
CM 321-188					5.7			0/1
CM 430-37				7.0				1/1
CM 489-1	7.6	7.2			8.3	15.6	4.3	3/5
CM 507-34		8.2						1/1
CM 507-37	10.8	10.7	3.3	9.0	5.4	12.2	6.2	5/7
CM 516-7					6.0	11.7		1/2
CM 517-1		4.3						0/1
CM 523-7	10.5	12.2	3.0	7.3	4.1	13.5	4.7	5/7
CM 723-3	10.6	8.3				13.0		3/3
CM 849-1	7.0	8.3			10.7	17.5		3/4

[a] Town, department and planting season

[b] Proportion of sites in which yield equalled or exceeded trial mean, compared to total number of sites planted.

Table 18b. Continued.

Clone	La Libertad, Meta (A)	San Martin, Meta (A)	Carimagua, Meta (A)	Carimagua, Meta (B)	CIAT-Palmira, Valle (A)	Quilichao, Cauca (A)	Mondomito, Cauca (A)	Relative Performance
CM 922-2	6.9	5.7			6.9	13.6		2/4
CM 946-2	4.3	4.8				10.8		0/3
CM 955-2	8.9	5.9			8.6	14.4		3/4
CM 962-4					8.6	14.8		2/2
CM 981-8					5.8	11.9		0/2
CM 996-6	8.3		2.2	9.1				2/3
CM 1016-4					3.9			0/1
CM 1016-31						13.1		1/1
CM 1022-4					3.4			0/1
CM 1305-3					11.3			1/1
CM 1335-4	4.5	7.5						1/2
CM 1355-4		3.4		10.6				1/2
CM 1559-5			2.9					1/1
CM 1585-13			3.0					1/1
CM 1989-4			4.2					1/1
CM 2068-7			2.6					0/1
CM 2086-7			2.2					0/1
CM 2086-16			4.1					1/1
CM 2088-1			3.1					1/1
Regional Varieties								
Algodona							8.0	1/1
Americana							8.5	1/1
Batata							7.1	1/1
Chiroza	7.8	8.0						2/2
Llanera	5.4	7.9		3.2				1/3
Popayan							8.1	1/1
Reg. Amarilla							5/3	0/1
Reg. Negrita							11.3	1/1
Sata Dovio							7.7	1/1
Seleccion 40							4.7	0/1
Valluna					1.7	6.3	7.1	1/3
Trial mean:	7.5	7.4	2.9	5.4	5.9	12.4	6.2	

Table 19. Correlation matrices for root dry yield for regional trials, 1983-84.

	Albania	Montañita	Carranzo	Pivijay	Sabanalarga
Laberinto	0.80**	0.86**	0.73**	0.38	0.15
Albania		0.77**	0.52	0.29	0.06
Montañita			0.34	0.45	-0.14
Carranzo				-0.13	0.26
Pivijay					-0.33

	San Martin	Carimagua (A)	Carimagua (B)	CIAT-Palmira	Quilichao	Mondomito
La Libertad	0.56*	0.96*	0.55	-0.35	0.03	0.78
San Martin		0.91*	-0.23	-0.10	0.03	0.58
Carimagua (A)			0.33	-	0.07	-
Carimagua (B)				-	0.59	-
CIAT					0.86**	0.14
Quilichao						-0.09

Figure 1. Monthly rainfall distribution in Colombian selection sites during 1983-84 growing seasons.

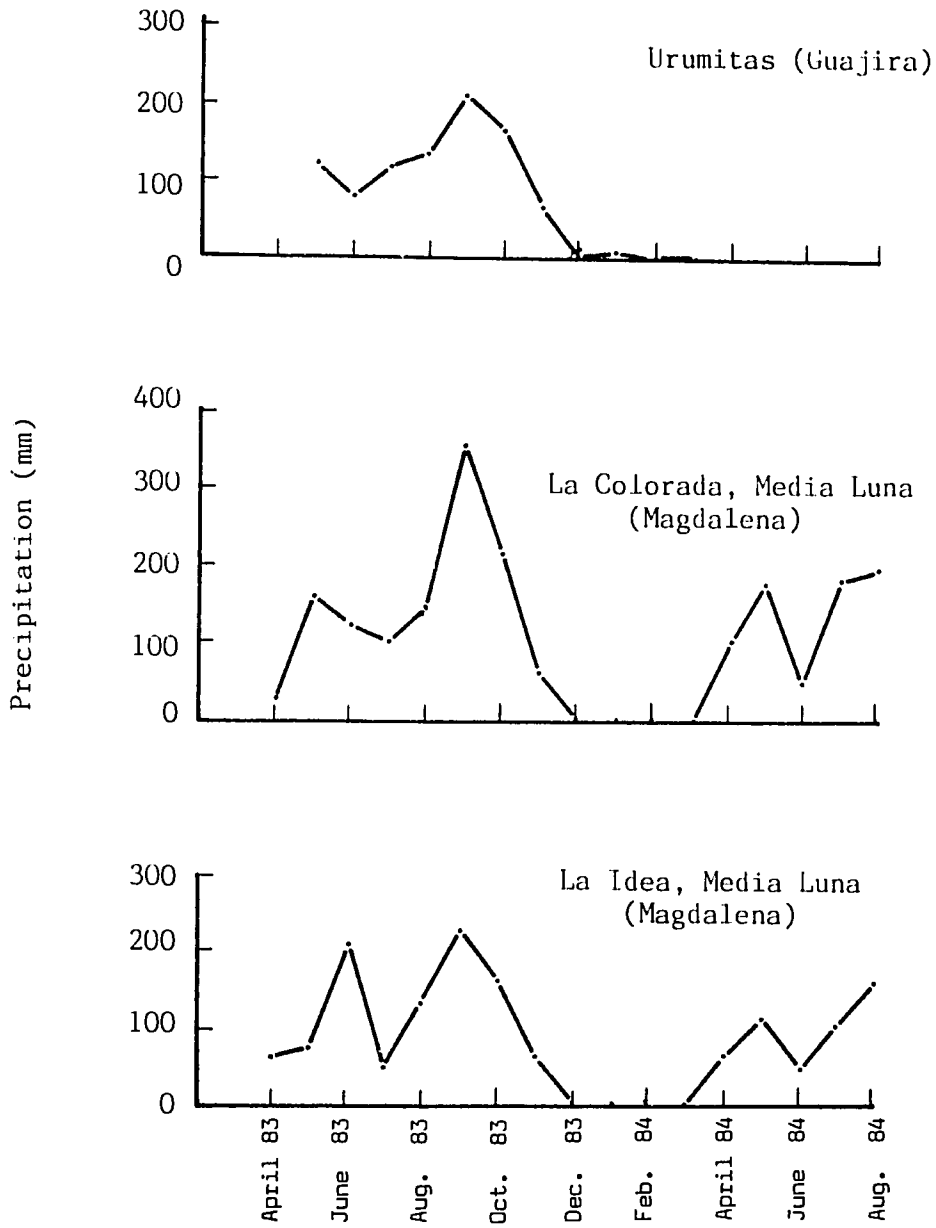


Figure 1. Continued

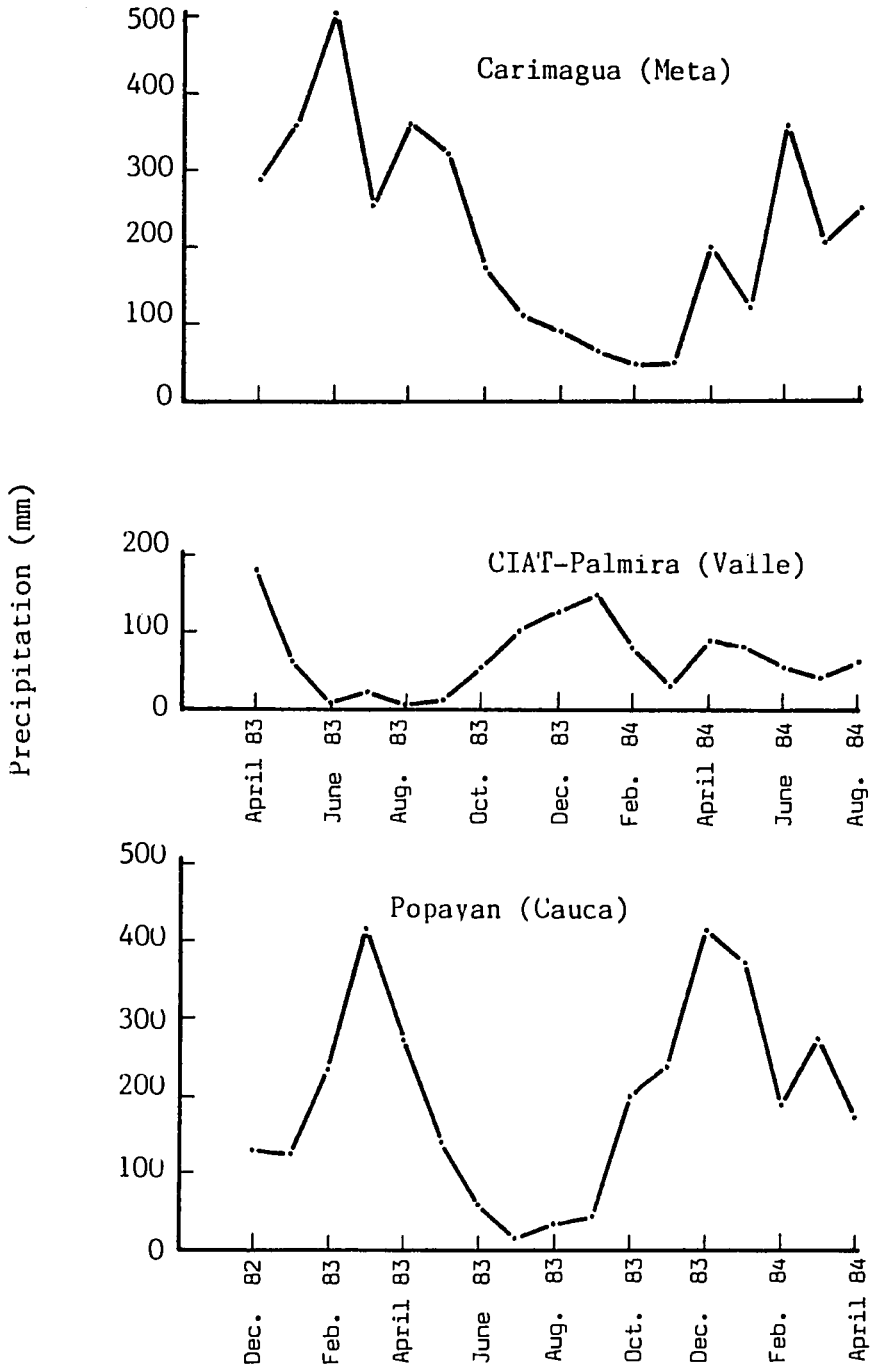
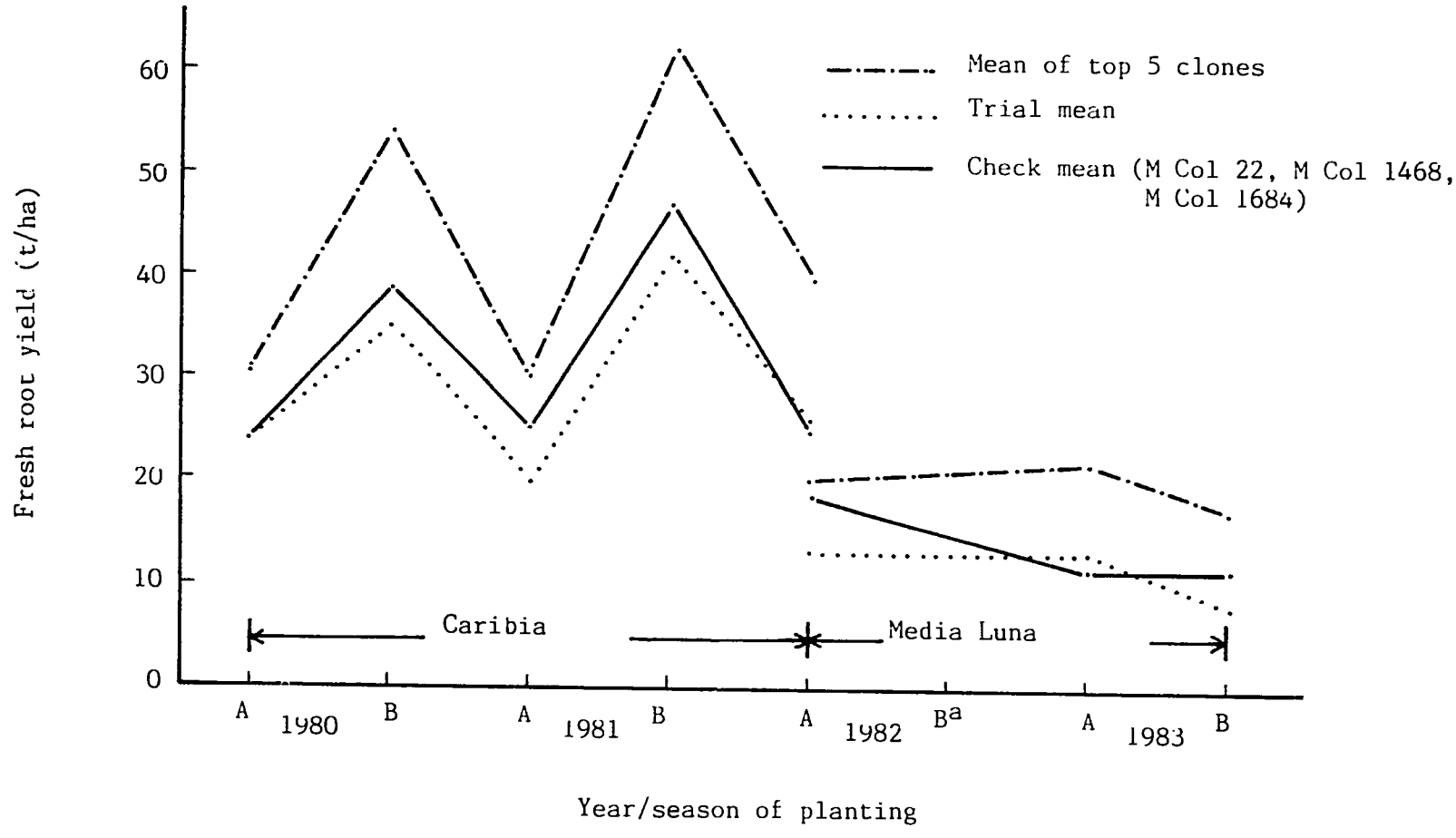


Figure 2. Yield trends in Atlantic coast region in advanced yield trials.



[a]No trial planted

Figure 3. Yield trends in Carimagua advanced yield trials.

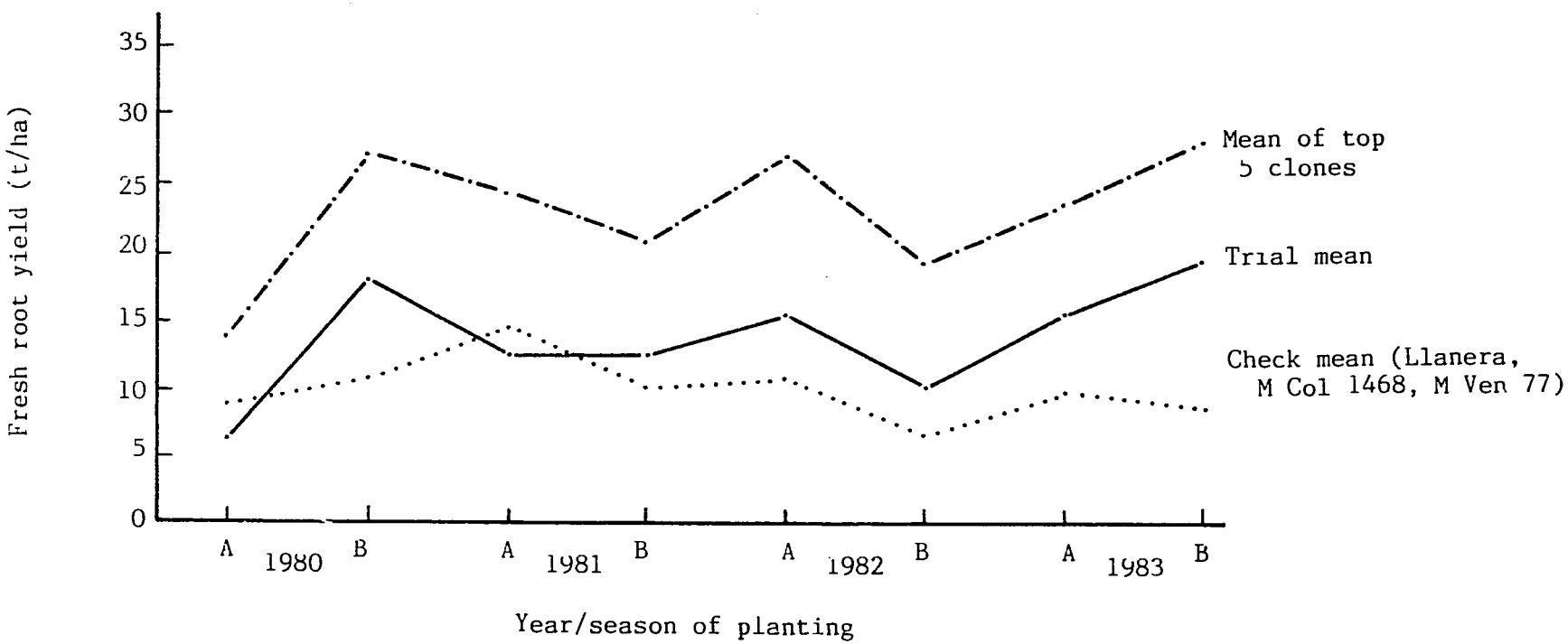


Figure 4. Dry root yield changes over four harvest dates for three clones under different acaricide/irrigation treatment combinations, Urumitas, the Guajira.

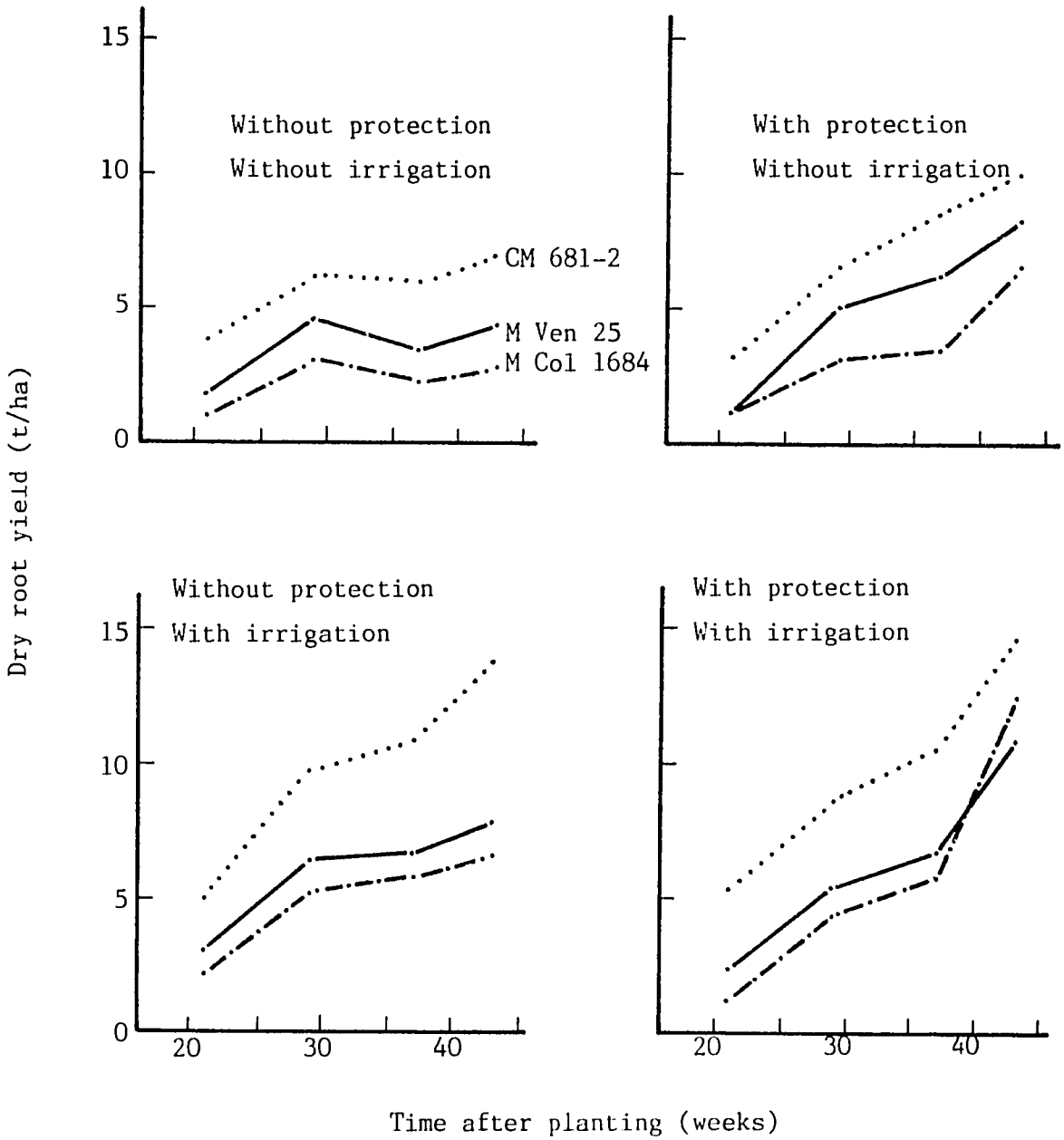
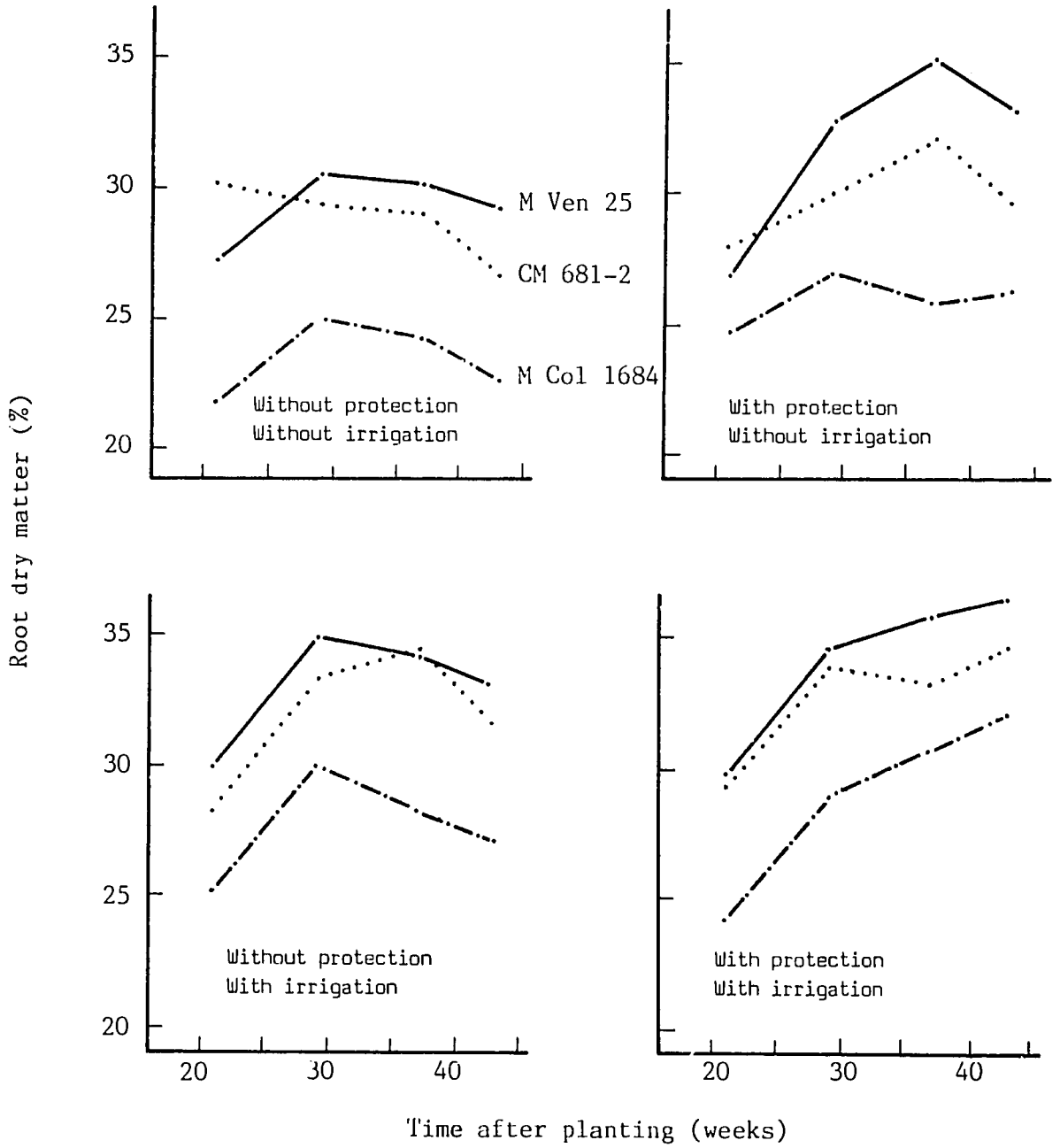
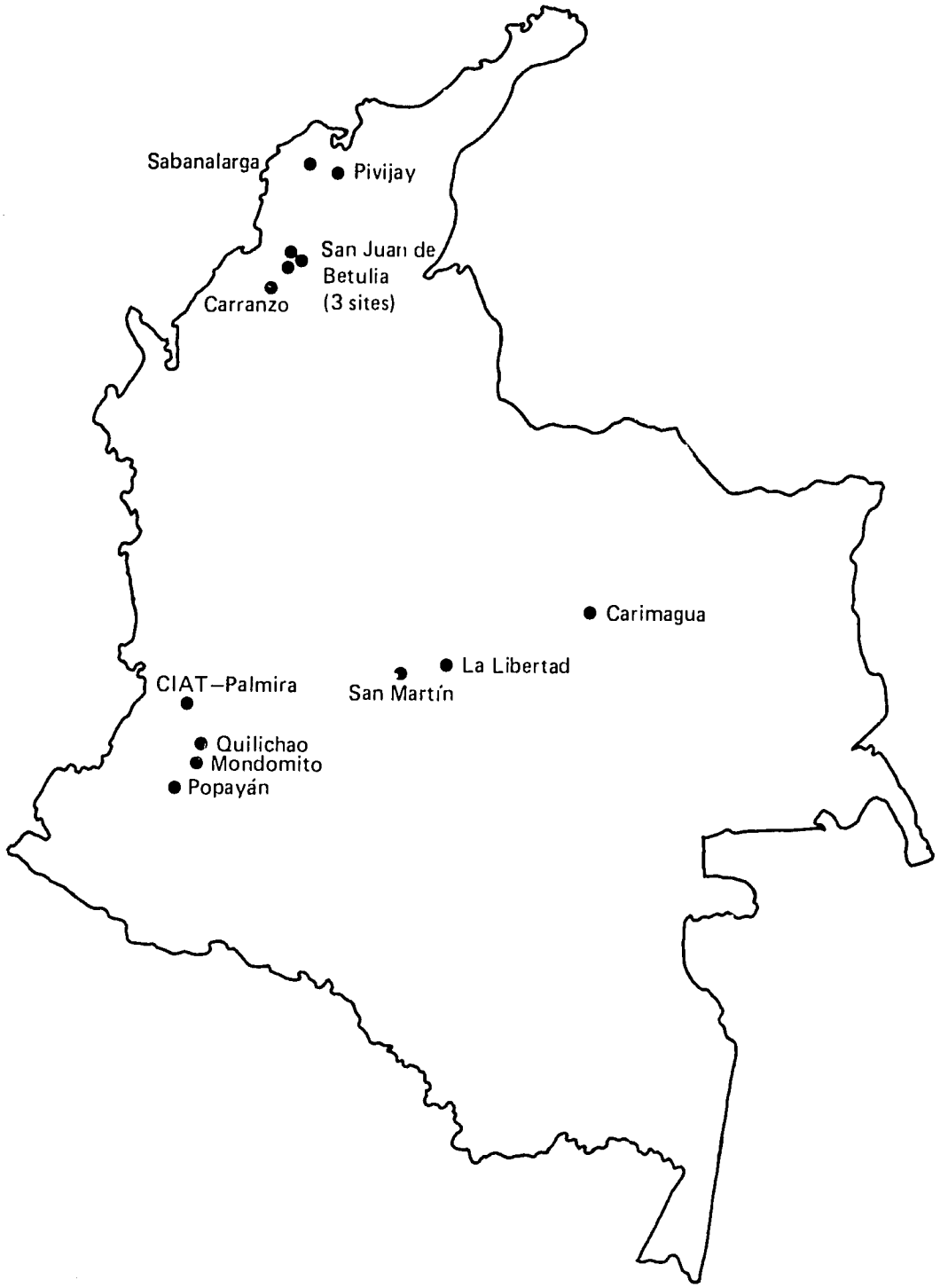


Figure 5. Changes in root dry matter content over four harvest dates for three clones under different acaricide/irrigation treatment combinations, Urumitas, the Guajira.




Sabanalarga
Pivijay
San Juan de
Betulia
(3 sites)
Carranzo
Carimagua
La Libertad
CIAT–Palmira
San Martín
Quilichao
Mondomito
Popayán

TISSUE CULTURE

In 1984, the work on tissue culture concentrated on two main areas: (a) *in vitro* clonal propagation using meristem culture techniques, to produce healthy clones, to exchange germplasm internationally and to conserve germplasm. These applications are shown in Figure 1; and (b) development of a tissue culture cycle and plant regeneration in cassava, using protoplast and callus culture techniques to explore somaclonal variability, "haploid" production, and transformation.

Recovery of Healthy Clones

The cleaning technique developed earlier continued to provide healthy material for the following purposes: (a) distribution of elite clones, (b) multiplication and testing by breeders of newly introduced clones, (c) recovery of pest-damaged clones from the germplasm bank and (d) provide basic planting material to the Cassava Program for performance trials. Indexing of clones after meristem culture (e.g. newly introduced germplasm) or before meristem culture (e.g. elite clones and germplasm bank material) has been carried out routinely by the programs's virology section.

The number of clones cleaned this year are shown in Table 1.

While the production of clones free of the so-called syndrome is necessary to study its nature. Attempts to clean up several segregating lines of the so-called ET syndrome by thermotherapy (low or high temperature) followed by meristem-tip culture continued to give negative results.

Work has been initiated to find out whether somatic embryogenesis eliminates the syndrome. If somatic embryos originate from single cells in cassava, and if the syndrome is caused by a pathogen-like organism, some regenerated plants should be free of the syndrome.

International Exchange of Germplasm

Distribution from CIAT

As shown in Table 2, 638 cassava materials, comprising both elite clones and germplasm accessions were sent *in vitro* to 21 countries in 1984.

Introduction to CIAT

In collaboration with the national programs of four countries and the International Board for Plant Genetic Resources (IBPGR), 240 cassava clones were introduced to CIAT in 1984 using *in vitro* techniques, as shown in Table 3.

Wild Manihot Species

Approximately 100 wild *Manihot* spp. are distributed in the major centers of diversity, i.e., from Mexico to Paraguay and northern Argentina. As was indicated in the 1983 Cassava Annual Report the utilization of wild *Manihot* germplasm in the genetic improvement of cassava is restricted because of problems encountered in collection and propagation such as scarcity of seeds and/or stem cuttings, poor rooting and sprouting of cuttings or very low seed germination are restrictions.

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At the same time, current meristem tip culture techniques used with cassava do not function as well with wild Manihot species. Therefore, research has been carried out to develop embryo and shoot-tip culture techniques for micro propagation of wild Manihot spp. Pre-treatment of seeds at 60°C for two weeks was beneficial to embryo germination. Using a modified MS medium supplemented with AG, thiourea and sucrose, embryo germination and plant development was achieved in 10 wild Manihot spp.: M. aesculifolia, M. cecropiaefolia, M. divergens, M. carthagenensis, M. caerulus, M. caudata, M. chlorosticta, M. glaisiovi, M. michaelis.

Figures 2A-D and 3A-D show various stages in embryo culture, germination, seedling growth and potting.

Germplasm Conservation

Limited growth storage

This year, the number of cassava clones placed into in vitro storage has reached 2,155, or 58% of CIAT's current collection.

The cassava clones stored in vitro are listed in Table 4 indicating their source country.

Cryogenic storage

Following retrieval from liquid nitrogen, 200 cultures of seven cassava clones were transfered to CIAT from the Plant Biotechnology Institute in Saskatoon, Canada. These clones have been propagated in vitro, then planted in the filed along with conventionally propagated stakes. Phenotypic stability of these clones is being evaluated using morphological, agronomic and biochemical criteria.

Evaluation of Phenotypic Stability of Clones Retrieved from Minimum Growth Storage.

Five cassava clones (M. Mex 20, M. Col 650, M. Col 2497, CM 305-38 and CM 323-375) were retrieved from minimum growth storage after 42, 1[illegible], 18, 30 and 30 months, respectively. After micro propagation by nodal cuttings, the clones were transplanted to the field along with two types of control plants: meristem culture-propagated plants and plants conventionally propagated by stakes. Phenotype stability was evaluated on the bases of morphological, agronomic and biochemical criteria.

Morphology.

Some of the parameters evaluated are shown in Table 5, along with the results of the morphological and agronomic evaluation in the 5 cassava clones significant variations were found in four characters only in M. Mex 20. Clearly, the deeper green color of leaves as well as the 30% larger petioles and leaves are due to passing the plants through an in vitro stage prior to their storage or simple micro propagation. However, in vitro storage, but no simple meristem culture, was the cause of root epidermis and cortex variation in color. All other morphological descriptors evaluated remained unaltered in the other four clones.

Agronomy.

Some of the agronomic parameters are listed in Table 5 together with the results. Again, only the clone M. Mex 20 showed variation in plant height as well as in the height at which the first branching occurred.

Storage derived and meristem-cultured plants were 85% and 62% taller respectively than stake-propagated plants. Although yield of fresh roots was significantly higher *in vitro* processed plants of clones M. Mex 20 and M. Col 650, it was quite low in the other three clones. However, the harvest index in all five clones increased as one passed from stem cutting propagation to meristem culture and to *in vitro* storage. This shows that *in vitro* processing resulted in more efficient distribution of growth (Table 5).

Biochemistry.

Extracts of five different plant tissues obtained from stake sprouts were run through starch gel electrophoresis using five buffer systems. Gel slices from each tissue and buffer system were stained for 16 isozymes. Out of these trials, 12 isozymes, two buffer systems and two tissues (young nodes and root tips) were chosen for phenotypic evaluation (Table 6).

Differences in the banding patterns of different cassava cultivars (Figure 4ABC) were evident for several isozymes. However, gels from different plants of the same clone showed no differences at all. This demonstrates the validity of the technique for genotyping.

Gels of plants retrieved from *in vitro* storage, meristem-tip propagation and stake-propagation of each of the five clones, and with each of the 12 isozymes, were the same in their electrophoretic patterns (Figure 5).

With the exception of a change in the color of root epidermis and cortex, no other changes have resulted solely from *in vitro* storage in any of the morphological, agronomic and biochemical characters evaluated. The morphological changes observed in the clone M. Mex 20 can be attributed to the elimination of the frog skin disease, achieved by passing the plants through *in vitro* culture. Here, alterations in morphology were accompanied by increase in vigor and yield. Clones M. Col 650 also showed a yield increase but not morphological changes. Interesting, all clones showed a higher harvest index as a consequence of *in vitro* culture.

Evaluation of these materials in a second growth cycle should confirm their phenotypic stability.

The research on electrophoretic isozyme analysis of cassava continues under a special project with International Development Research Centre (IDRC) at the University of Manitoba at Winnipeg, Canada. For the short term, methodologies should be sufficiently developed for application in sorting out duplicates in the collection, clustering germplasm accessions, and eventually in looking for genetic markers.

Table 1. Clones cleaned by meristem culture in 1984.

Cleaning for	No. clones
From frog skin disease	31
Mealybug attack (germplasm bank)	53
Cleaned vs. non-cleaned parents trial	43
Clones introduced from Costa Rica	94
TOTAL	221

Table 2. Distribution of elite clones and accessions from the germplasm bank by country.

Country	No. clones	No. accessions
Argentina	12	47
Bahamas	7	46
Barbados	15	44
Brazil	7	26
Canada	12	24
Cuba	432	1,417
Costa Rica	8	39
Ecuador	12	58
Egypt	17	84
United States	2	10
Guatemala	3	9
Honduras	10	51
Indonesia	5	43
Jamaica	3	10
Mexico	12	47
Panama	15	36
Peru	3	9
Philippines	15	64
Thailand	9	44
Trinidad	16	44
Venezuela	23	129
TOTAL	638	2,281

Table 3. No. of clones introduced to CIAT by source country.

Source country	Collaborating institute	No. clones
Costa Rica[a]	CATIE	130
Guatemala	Universidad San Carlos	90
Panama	IDIAP	18
Philippines	VISCA	2
	TOTAL	240

[a] Indexing of cultures resulted completely negative for Caribbean Mosaic Virus (CMV).

Table 4. No. of clones *in vitro* by source country as of 1984.

Source country	No. clones
Argentina (M. Arg)	16
Bolivia (M. Bol)	1
Brazil (M. Bra)	725
Colombia (M. Col)	802
Costa Rica (M. CR)	130
Cuba (M. Cub)	16
Ecuador (M. Ecu)	16
Philippines (M. Fil)	2
Guatemala (M. Gua)	90
Malaysia (M. Mal)	2
Mexico (M. Mex)	32
Panama (M. Pan)	27
Paraguay (M. Par)	97
Peru (M. Per)	154
Puerto Rico (M. PTR)	3
Dominican Republic	1
Thailand (M. Tai)	1
Venezuela (M. Ven)	40
TOTAL	2,155

Table 5. Morphological and agronomic characters showing variation in plants regenerated from *in vitro* storage as compared to plants propagated by meristem culture and stakes.[a]

Parameter	Cultivar	*In vitro* stored plants	Meristem culture propagated plants	Stake propagated plants
Morphological				
1. Color apical Leaf	M Mex 20	dark-green	dark-green	light green
2. Petiole	M Mex 20	25.8	25.7	19.9
3. Color root epidermis	M Mex 20	light brown	white	white
4. Color root cortex	M Mex 20	yellow	white	white
Agronomic				
5. Plant height (m)	M Mex 20	2.8	2.8	1.8
6. Height of stem at 1st branching (m)	M Mex 20	2.4	2.1	1.3
7. Yield fresh root (t/ha)	M Mex 20	29	30	14
	M Col 650	23	19	17
	M Col 2197	7	6	21
	CM 305-38	23	24	38
	CM 323-375	11	18	26
8. Harvest index	M Mex 20	0.5	0.4	0.4
	M Col 650	0.7	0.6	0.3
	M Col 2197	0.6	0.5	0.5
	CM 305-38	0.8	0.7	0.7
	CM 325-375	0.6	0.6	0.5
9. Frog skin	M Mex 20	-	-	+
	M Col 650	-	-	+
	M Col 2197	-	-	-
	CM 305-38	-	-	-
	CM 325-375	-	-	-

[a] From a total of 10 morphological and six agronomic parameters evaluated.

Table 6. Isozymes and buffer systems for evaluation of cassava stored *in vitro*.

Isozymes	STD	PC
Acid phosphatase (AcP)	+	
Alcohol dehydrogenase (ADH)	+	
Glutamate-oxaloacetate-transaminase (COT)	+	
Glutamate dehydrogenase (GDH)		+
Isocitric dehydrogenase (IDH)		+
Malate dehydrogenase (MDH)		+
Malic enzyme (ME)	+	
Peroxidase (Prx)	+	
Phosphogluco-isomerase (PGI)	+	
Phosphogluco-mutase (PGM)		+
6-phosphogluconate dehydrogenase (6-PGDH)		+
Shikimic dehydrogenase (SKDH)		+

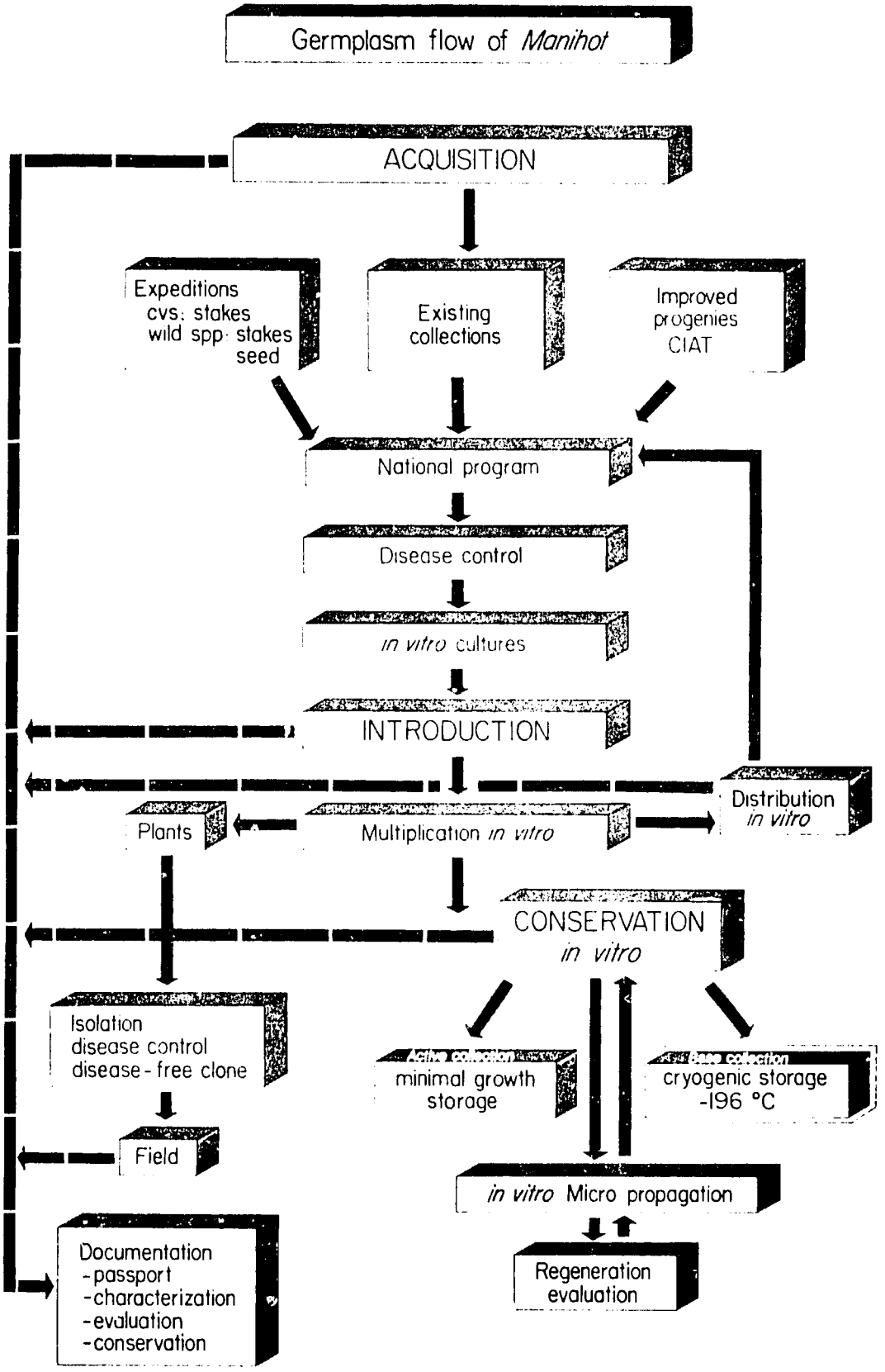

Figure 1. Utilization of Tissue for Clonal Propagation of Cassava (Manihot esculenta) Germplasm.

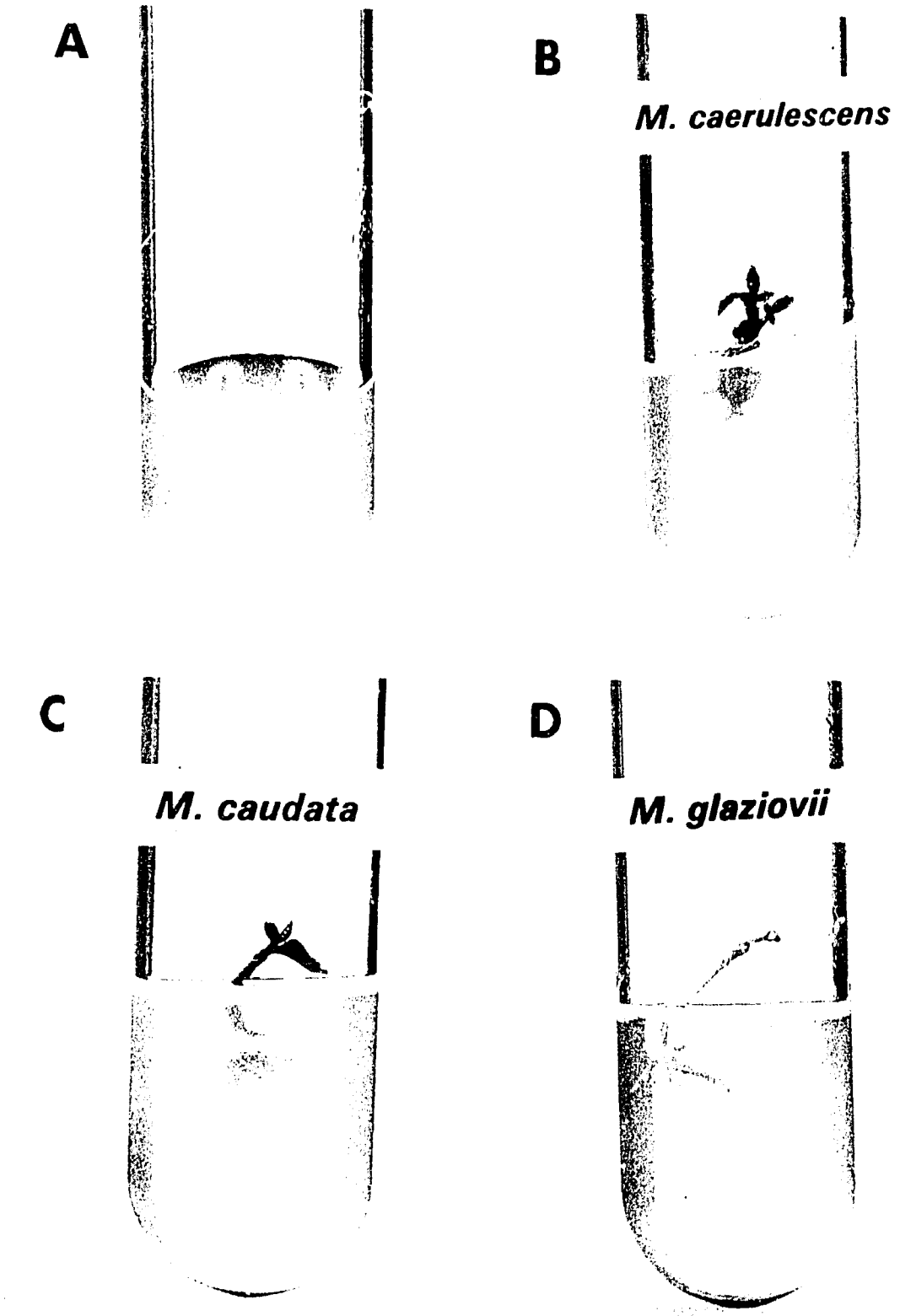

FIGURE 2. Embryo culture of wild Manihot spp.

A. Excised embryo in culture.

B,C,D. *in vitro* embryo germination of wild species.

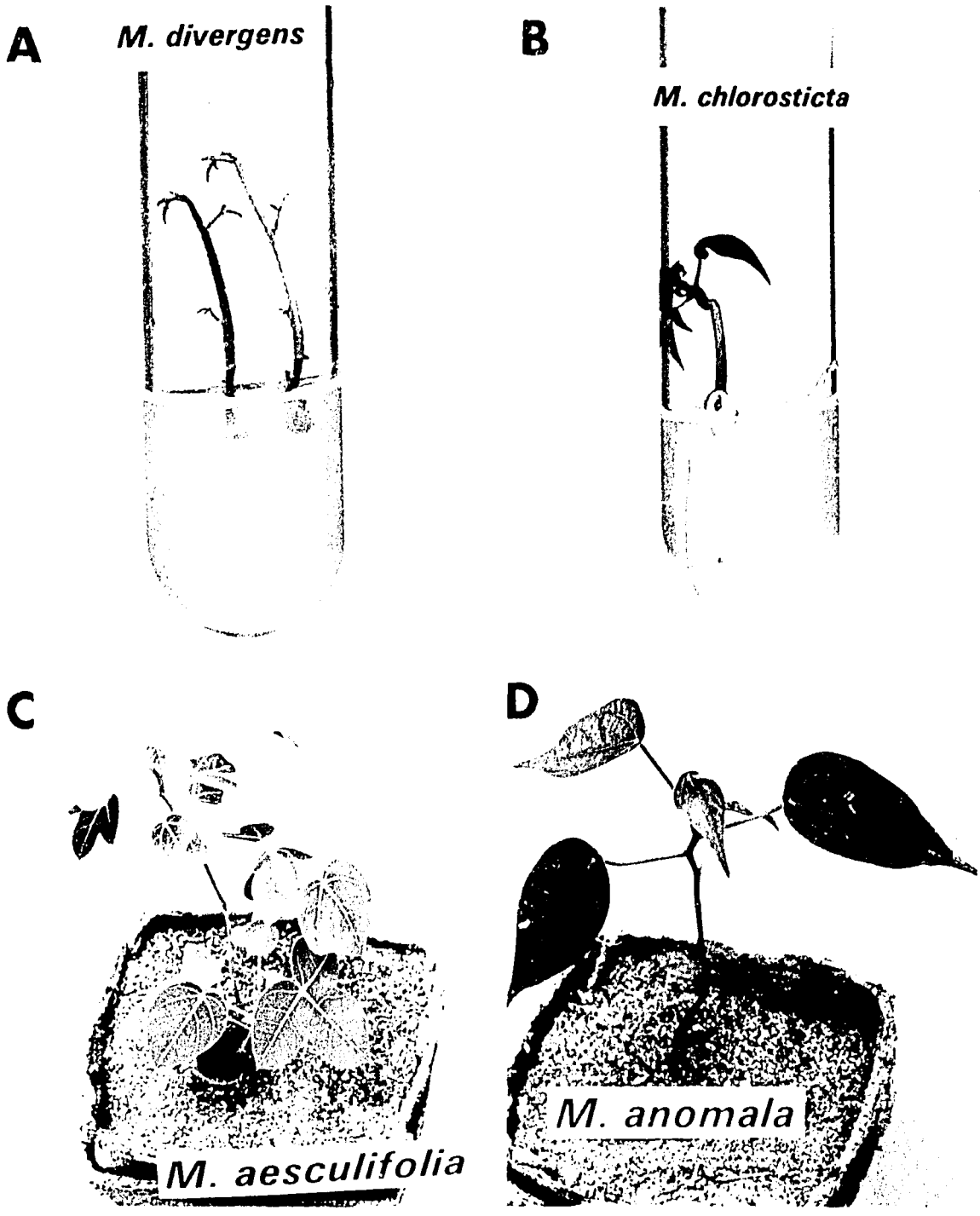

FIGURE 3. Same as Fig. 2

A. and B. in vitro embryo germination

C. and D. potting of embryo-derived plants.

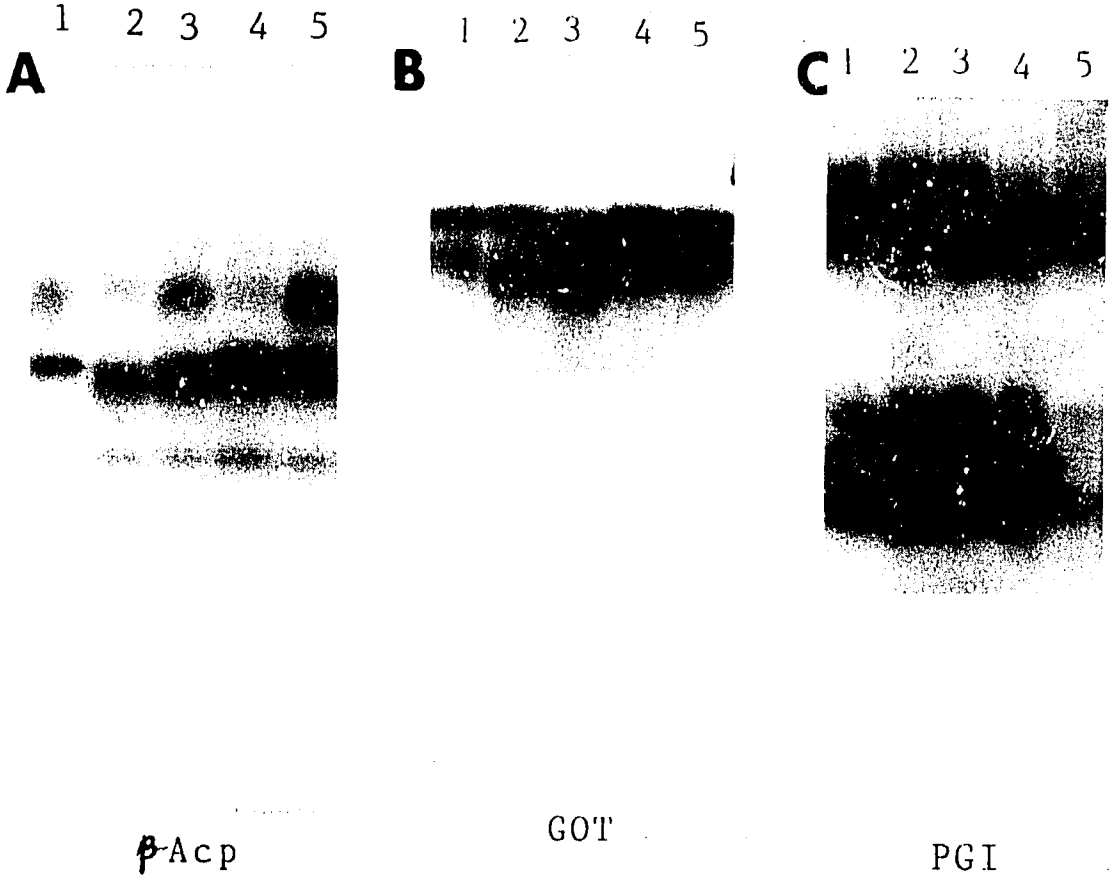

Figure 4. Genotype finger printing of cassava clones by starch electrophoresis.

1, 2, 3, 4, 5: cassava clones

A. Acid phosphatase

B. Glutamate-oxaloacetate-transaminase

C. Phosphogluco - isomerase

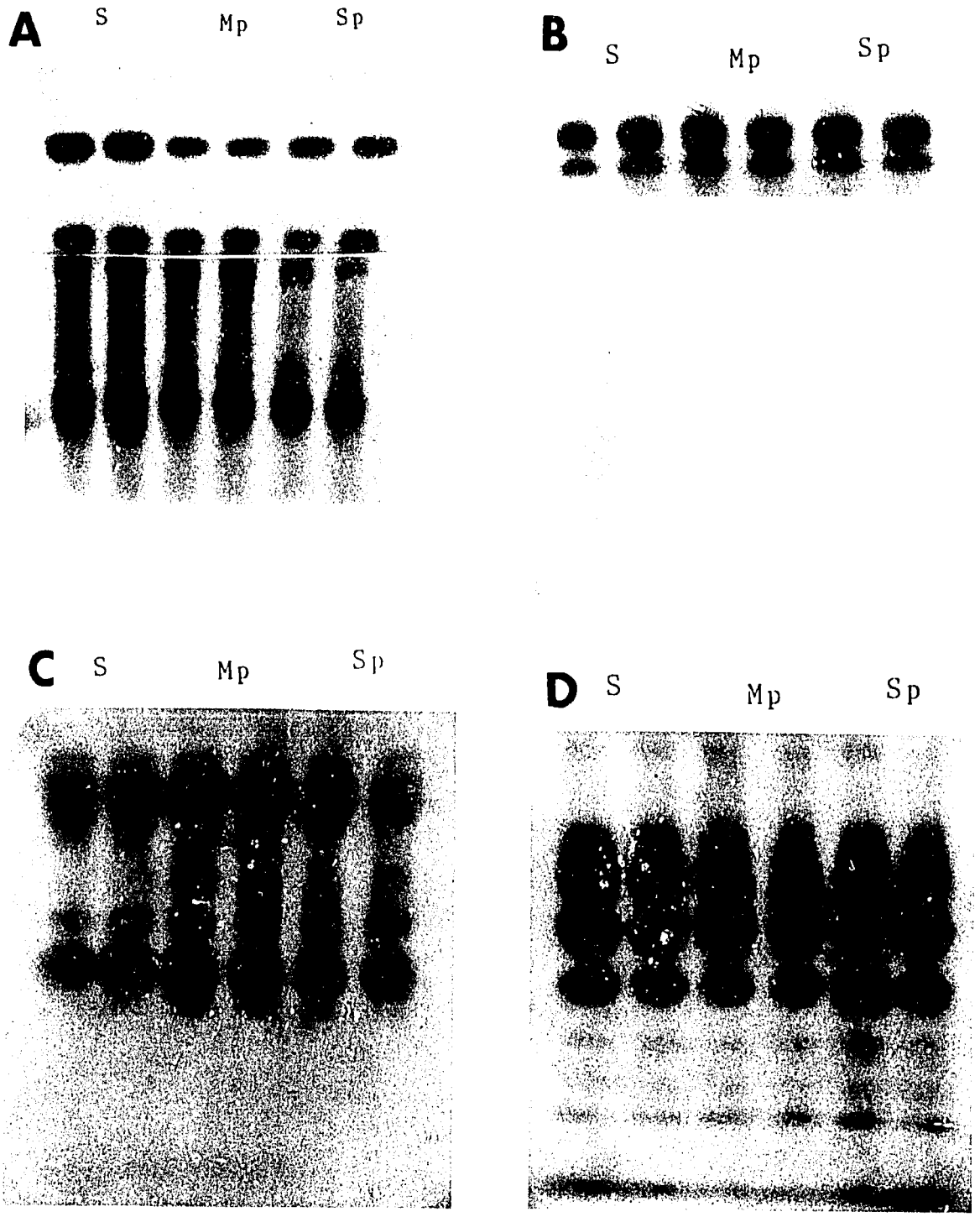

Figure 5. Isozyme patterns of cassava clones stored *in vitro* (S), propagated by meristem culture (Mp) and by stakes (Sp).

A. M. Mex 20 (peroxidase)
B. M. Col 2197 (phosphoglucomutase)
C. CM 305-38 (phosphpisomerase)
D. CM 323-375 (α,ß-acid phosphatase)

Protoplast Culture

Implementation of novel approaches to plant cell genetics and crop improvement requires an efficient "protoplast system", i.e. reproducible techniques for the regeneration of functional plants from isolated protoplasts. The failure of plant regeneration from isolated cassava protoplasts has been recognized as a major deterrent to the utilization of protoplasts in breeding programs of this important crop. The only known result in cassava protoplast culture is the sporadic shoot formation in leaf protoplast-derived calli achieved by Shahin and Shepard at Kansas State University.

However, the research program, established at CIAT aims for the development of an efficient protoplast regeneration system of cassava.

Plant material used for protoplast isolation

Young, fully extended leaves of meristem cultured plantlets, were used for protoplast isolation. *In vitro* plantlets were propagated by nodal cuttings. Shoot tips leaf lobes of the *in vitro* grown plantlets and embryonic calli were used also in several experiments. Leaves of greenhouse grown plants were discarded because of the high rate of contamination.

The following cassava varieties have been used successfully for protoplast isolation and culture experiments: M Col 22; M Col 1505; M Col 1438; M Col 1684; CMC 40; M Mal 1; M Col 1940; M Col 2017; M Bra 739; M Per 102, and the wild species *M. cecropiaefolia*.

Isolation of protoplasts

Young leaves of 1-1.5 month old plantlets were washed with 30% alcohol and then several times with sterile destilled water to remove the cuticle. After rinsing, the leaves were transferred to 0.4 M solution (0.4 M Mannitol; 50 mM $CaCl_2$, 10 mM KH_2PO_4 pH 5.6), and were cut into 1-3 mm pieces. The 0.4 M solution was then replaced by the protoplast isolation medium, and the leaf pieces were incubated at 25°C for 12 14 h.

The isolation medium was a mixture of one part enzyme solution (3% Onozuka R-10 cellulase, 1% Hemicellulase, 0.3% Pectolyase Y23) and three parts protoplast culture medium (see section on "Culture Media Used"). The composition of the enzyme solution was established according to the results of preliminary experiments. Twelve combinations of five different enzymes and Mannitol concentrations of 0.2 - 0.7 were tested.

This isolation procedure released healthy protoplasts containing bright green chloroplasts arranged on the periphery (Figure 6A).

After digestion, the debris were removed by filtration through a 80 m size Nylon filter and the protoplasts were purified by subsequent centrifugation steps. The purified protoplasts were finally resuspended in the culture medium.

Culture of isolated protoplasts

Protoplasts were cultured in 200-250 l drops of liquid media in 60 x 15 mm plastic petri dishes. The culture dishes were sealed with parafilm and cultured at 26°C in the dark.

The protoplasts regenerated cell walls within 48h and changed the spherical shape to elongated or oval. The first cell divisions were observed after 3-4 days of culture. Subsequent divisions lead to colony formation in the following two weeks (Figure 6B and C).

Culture media used.

Several culture media were tested for culturing cassava protoplasts, including the medium used by Shahin and Shepard. The culture efficiency was estimated on the basis of the division frequency of the cultured protoplasts:

$$\text{Division index} = \frac{\text{No. of dividing protoplasts}}{\text{No. of cultured protoplasts}} \times 100$$

The medium of Kao (as described in Table 1) was found to be superior for culturing cassava protoplasts, although good culture efficiency has been achieved in the less complex B5 or V47 media, containing 250 mg/l case in hydrolysate as organic additive and 0.4 M glucose as osmotic stabilizer. The culture medium used by Shahin and Shepard for cassava protoplasts (medium C1) resulted in lower culture efficiency in the experiments (Table 1).

Effect of growth hormones

The presence of growth hormones in the culture medium is generally indispensable for triggering protoplast divisions. Twenty-four combinations of cytokinins (Zeatin, Kinetin, Benzyladenine) and auxins (NAA, IAA and 2,4-D) were evaluated. A combination of 1 mg/l NAA, 0.2 mg/l 2,4-D and 0.5 mg/l Zeatin was optimal for induction of cell divisions.

Protoplast culture density

It is well known, that cell population density affects the protoplast's division response. When different population densities were compared the highest division frequency was found at 2-3 x 10^4 protoplast in different culture media (Figure 7). The more complex Kao medium permitted protoplasts to divide at lower densities than the relatively simple B5 medium. When protoplasts were incubated initially at optimal densities, it was possible to dilute the culture 30-50 times after the first divisions started. The low density of cells permit the isolation of single cells by micropipettes or micromanipulator, and culture the colonies individually and the single-cell cultures are important in cell genetic manipulations. If no selective genetic markers are available, the fused heterokaryons or protoplasts injected with foreign DNA are expected to separate and culture individually.

Effect of genotype

Experiments made with different cassava varieties led to the conclusion that genotype has an important role in the culture efficiency of the protoplasts.

Highest division rates up to 30% were observed with protoplasts of cultivars M Col 22 and M Col 2017. Other varieties expressed less efficient protoplast culture: 10-15% of the cultured protoplasts divided at optimal circumstances.

Choice of proper varieties can have crucial role in the success of the experiments attempting plant regeneration (see below "Somatic Embryogenesis of Cassava").

Culture of the Protoplast-Derived Colonies

Serial and gradual addition of fresh medium with reduced glucose levels was necessary for rapid and healthy growth of protoplast derived cells and colonies. Usually the original protoplast culture medium was used for the first dilution. Later, it was mixed with MS medium containing 2% sucrose and variable growth hormones. Up to 50-60% of the dividing cells developed into colonies. Rapidly proliferating colonies were transferred to a solid medium after 4-5 weeks of culture. Usually 1 ml of protoplast culture medium, containing 100-200 microcolonies, were pipetted on the surface of agar medium in 100 x 15 mm petri dishes. Different culture media were used to support further colony growth and to attempt the induction of somatic embryo or shoot formation. MS on D5 basic media were usually used, supplemented with 100-150 mg/l casein hydrolizate. Platting efficiency was higher when the media were solidified by 0.5 - 0.6% agarose instead of 0.8% agar (Figure 6D).

Up to now, 26 combinations of growth hormones (2, 4-D, NAA, IAA, Zeatin, Kinetin, BAP, GA3, ABA) and organic additives (glutamine proline, coconut water, adenine) have been tested in different experiments. At optimal circumstances 30-90% of the plated microcolonies formed calli.

These methods are now being used routinely for culture of cassava leaf mesophyll protoplasts. Further experiments are in progress to regenerate plants from the protoplast-derived colonies.

Somatic Embryogenesis of Cassava

Plant regeneration through somatic embryogenesis has been described in a number of plants. The goal is to establish a reliable plant regeneration system through somatic embryogenesis, suitable for use in cell genetic manipulations. These investigations are based on the results of researchers at the School of Biological Sciences, University of Bath, United Kingdom.

Initiation of embryogenic cultures

Embryogenic cultures were initiated from leaf lobes of *in vitro* grown cassava shoot cultures. Three 6 mm size leaf lobes were excised and placed on an induction medium, consisting of the basal medium of Murashige and Skoog, supplemented with 4 or 8 mg/l of 2,4-D (4-MS or 8-MS). Explants were incubated at 26°C in the dark for seven days and then transferred to continuous light of 2000 lux for a further 21 days. During this culture period, friable callus developed at the cut ends of the explants, and nodular structures appeared on the leaf surfaces (Figure 8A). The nodular structures could produce either somatic embryos or foliage structures. For further development of the somatic embryos,

the cultures were transferred to an MS medium supplemented with 0.1 mg/l BAP and 0.01 mg/l 2,4-D, and incubated in continuous light at 26°C.

Somatic embryo development was stimulated in this medium, and small plantlets emerged among the green foliage structures (Figure 8B+C). The plantlets could be separated and cultured in a 4E medium (routinely used for cassava meristem culture) allowing the development of standard shoot cultures and plants (Figure 8D). Developed plants could be potted and transferred to the greenhouse.

Induction of secondary embryogenesis

When embryogenic cultures or separated somatic embryos were transferred to the induction containing 2 or 4 mg/l 2,4-D, secondary embryogenesis could be observed on the cultures. Cultures were transferred to liquid induction medium and shaken (90 rpm). Fast proliferation of the embryogenic tissue was achieved by weekly subculture of cultures.

Secondary embryos, produced either in an agar solidified or in liquied medium, were transferred to a regeneration medium. A great amount of foliar structures were produced and some deformed and normal plantlets developed from the secondary cultures.

By regular subculturing of the secondary embryogenic tissues in induction medium, continuous proliferation of the secondary embryons was established. Whether these cultures maintain their embryogenic potential indefinetely is not know.

Somatic embryogenesis of different cassava varities.

Initial experiments had been performed with the cultivar M Col 1505. Recently, experiments were initiated using several cassava varieties. Great differences could be detected among the genotypes utilized regarding their capacity to produce somatic embryos (Table 2). Of 21 varieties, highest potential (more than 60%) was observed in 10 varieties; moderate capacity (30-50%) for embryogenesis occurred in seven and four varieties showed very low (less than 20%) embryo formation.

Morphological analysis of the regenerated plants

Because this is the first time that plants have been regenerated through somatic embryogenesis in cassava, it is important to ascertain whether the regenerated plants are true to type or not. Should the somatic embryogenesis system elicit variability (whether genetic or epigenetic) it could be utilized for selection of cassava somaclones with special attributes; if on the contrary, all plants remain true to type, the system could be scaled-upward for rapid multiplication of selected genotypes.

Somatic embryos of M Col 1505 have been received from the University of Bath. Following one *in vitro* propagation cycle (through nodal cuttings), three types of plantlets (on morphological characters) have been identified as resulting from the somatic embryos:
(a) dwarfed, rosette type, cultures with cotyledon-like leaves (3%);
(b) plantlets with all their leaves formed by a single lobule (12%);
(c) plantlets having leaves with 1, 2 and 3 lobules (75%);

(d) normal, true to type, plantlets (leaves formed by three lobules) (10%).

These morphological types remained unaltered following three cycles of *in vitro* propagation using nodal cuttings.

Another morphological variant has been observed in which the position of nodes (and leaves) is opposite-decusate instead of the normal helicoidal phylotaxis of cassava.

Whether these changes will remain stable after the plants have been moved to pots and the field has yet to be evaluated.

Table 1. Division rates of cassava protoplast in different culture media. All media contained 250 mg/l casein hydrolizate and 1 mg/l NAA, 0.5 mg/l Zeatin and 0.2 mg/l 2,4-D.

Media	B5p	MSp	V47	K	Cl-1	Cl-2	Cl-3	Cl-4
Division index (%)[a]	5.7	0.0	3.8	9.0	1.0	2.5	1.8	2.5

[a] The division index is an average of division frequencies detected in five independent experiments with the varieties: M Col 1438, CMC 40, M Col 22, M Col 1505, M Mal 1.

B5p: B5 Medium of Gamborg (1968) with 0.4 M glucose.

MSp: medium of Murashige & Skoog (1962) with 0.4 M glucose.

V47: medium of Binding (1974) with 0.4 M glucose.

K : medium of Kao (1977) (without the organic additivies) with 0.4 M glucose.

Cl-1: medium of Shahin and Shepard previously used for culture of cassava protoplast (1982).

Cl-2: as Cl-1 containing vitamins of B5.

Cl-3: Cl-1 with 0.4 M glucose as osmoticum

Cl-4: as Cl-2 with 0.4 M glucose

Table 2. Somatic embryogenesis in several cassava varieties.

Variety	Rate of somatic embryos (%) in	
	8-MS medium	4-MS medium
M Col 481	100	-
M Col 1940	90	-
M Per 302	88	-
M Col 1505	87	86
M Mex 59	82	29
M Col 1522	75	-
M Cub 74	66	-
M Ven 77	66	-
CMC 40	62	17
M Col 22	61	31
M Col 1684	56	-
M Arg 1	50	-
M Col 638	50	-
M Mal 1	47	-
M Col 1438	33	20
CM 430-37	33	-
M Col 1468	33	-
ICA HMC 1	20	-
M Col 2017	14	-
M Bra 739	0	-
M Arg 5	0	-

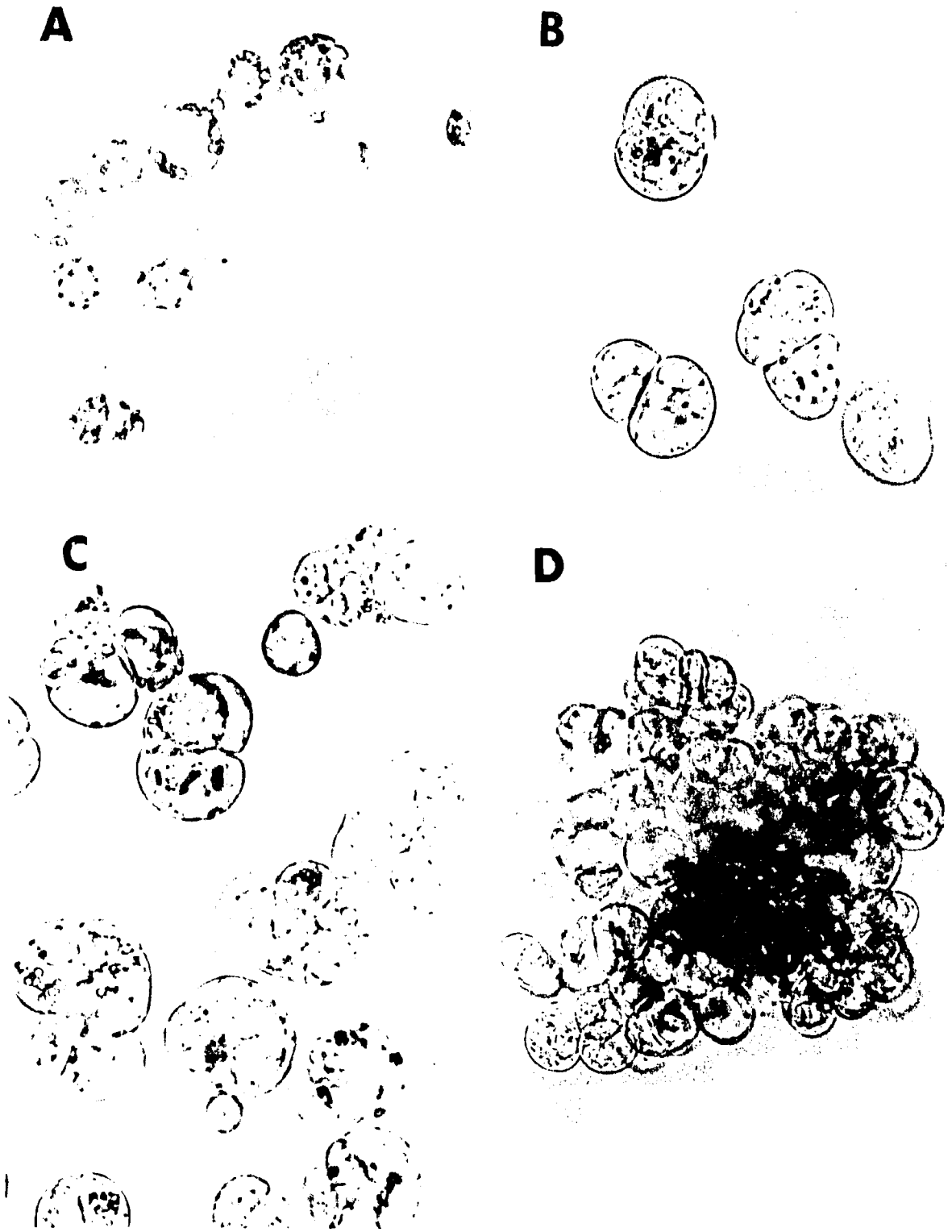

Figure 6. Cassava protoplast isolation and culture:

A. Freshly isolated leaf mesophyll protoplasts
B. First cell division observed in 6 day-old culture.
C. Subsequent divisions leading to colony formation.
D. Colony formation on media containing 0.8% agar and 0.6% agarose.

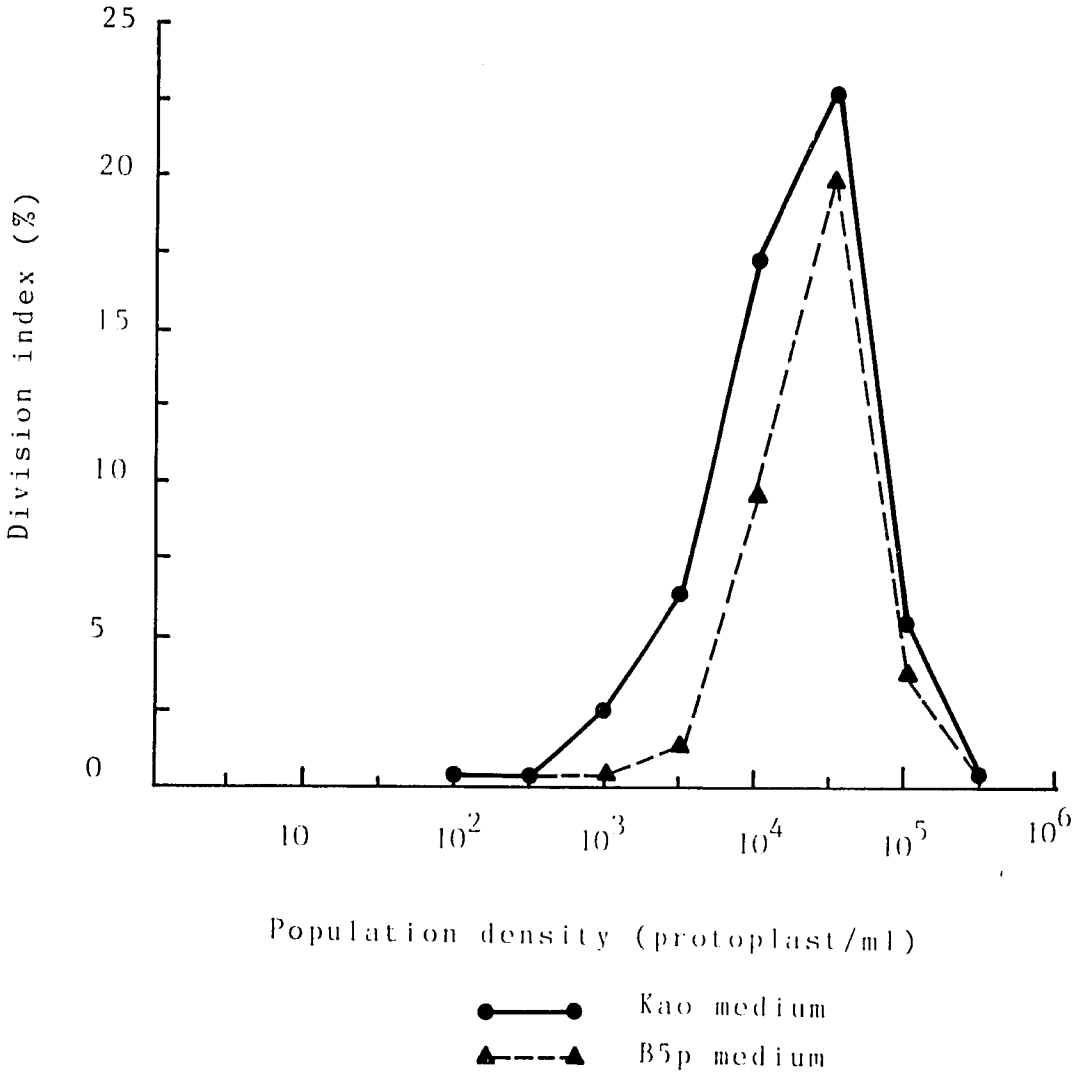

Figure 7. Effect of population density on the division frequency of cassava leaf protoplast (M. Col 22).

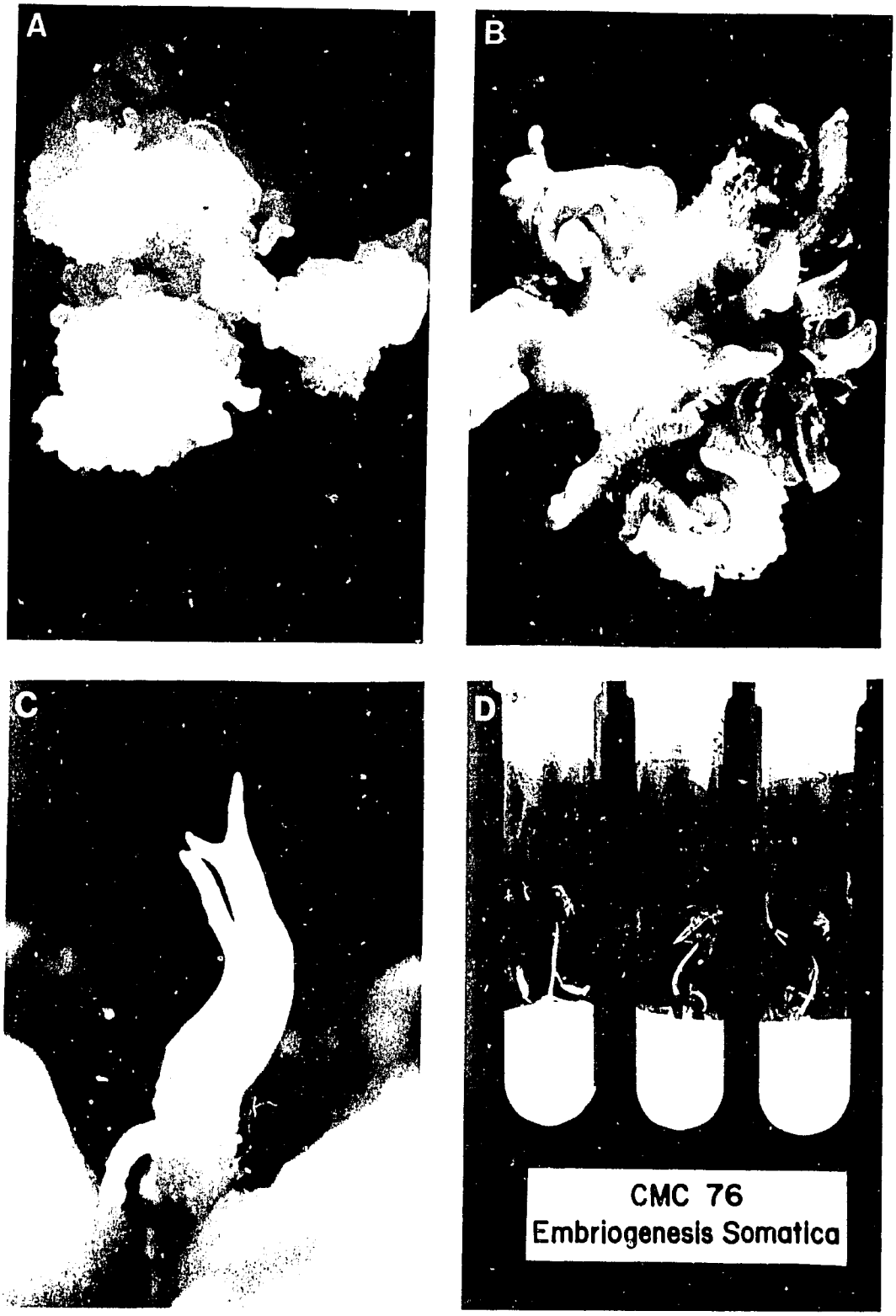

Figure 8. Somatic embryogenesis in cassava.

A. Nodular structures developing on leaf explants
B. Leafy structures developing from nodular cells
C. More developed somatic embryos (Torpedo, leafy)
D. Plants developed from somatic embryos.

CASSAVA UTILIZATION

During 1984 the cassava utilization section worked in two areas: (a) fresh cassava quality and storage; and (b) cassava drying.

(a) Fresh Cassava Quality and Storage [a]

In the 1983 Cassava Annual Report a description of a simple method of fresh cassava root storage, based on a chemical treatment plus polyethylene bag storage, was given together with the results of both CIAT based and on-farm methodology trials. This year the storage method has been tested in three other edaphoclimatic zones in which cassava is grown in Colombia, the treated roots have been analyzed for residues of the thiabenzole-based fungicide, and the quality of the stored roots has been consumer tested.

A new area of investigation was also initiated this year on the study of variation in various fresh root quality factors with respect to cultivar, plant age, climate, etc. and the relationships between these factors. This is important basic knowledge, since without knowing how root quality can be affected by climate, plant age or other factors, high quality stored roots cannot be reliably obtained.

Storage Trials In Colombian Cassava Production Areas.

Trials were conducted in three zones outside the Cauca Valley where last year's initial CIAT-based and on-farm studies were located. These zones were:

(1) The North Coast (Sucre and Atlantico departments).
(2) Carimagua, Llanos Orientales.
(3) Popayan, Cauca.

The North Coast is typical of many lowland areas of cassava production, the Llanos Orientales are also lowland but with higher rainfall, and Popayan is located at the high altitude extreme of cassava cultivation.

North Coast

These storage trials were carried out using commercially grown roots harvested at 11 months in February 1983. Roots were harvested between 6 and 8 A.M. and the experiments set up immediately. In one trial, roots contained in polyethylene bags were stored under a protecting roof with free air circulation below; in the other trial roots were stored in an enclosed room. The design was similar for each experiment: three bag sizes (for 1,5 and 20 kg of roots) were stored for one and two weeks before evaluation using both Mertect-treated and untreated roots. Roots were individually evaluated for both external microbial growth and for internal rotting. Of the two the latter is most critical. Physiological deterioration was almost invariably absent and

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[a] Project co-financed (until August 84) by the Tropical Development and Research Institute, TDRI, London and associated with Wye College, London University.

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this evaluation is, therefore, not presented here. Results are expressed on a scale of 0 to 100, where a value below 20 represents minor damage confined only to the two ends of the roots.

Table 1 presents the results of each experiment. While the storage environment was not critical in storage trials in the Valle del Cauca, a significant difference was observed between the open and enclosed storage sites in these trials on the North Coast. Where air circulation around the bags was possible, acceptably low losses were obtained. In the enclosed area however, the losses due to both microbial growth and to internal rotting were unacceptably high. This was due to the excessively high storage temperatures in these confined spaces. Unlike the Cauca valley, where the climate is more moderate (mean 23°C), the storage conditions here do appear to be critical.

The fungicide treatment was significant ($P = 0.001$) in reducing storage losses, in all bag sizes. Overall means for experiment 1 are given in Table 2.

The stored roots were found to be of good quality after informal evaluation by local farmers. There were no significant changes in root dry matter (DM) content during the two week storage period: the fresh roots (35.3% DM) fell in the middle range of DM values of the stored roots (33.7 - 36.1%).

Carimagua

One storage experiment was carried out during April 1984, in which three cultivars (M Ven 77, M Col 1916 and M Pan 19) were stored in 5 kg bags for one and two weeks. Roots, both treated and untreated with Mertect, were stored. Results (Table 3) clearly show the great reductions in losses in the Mertect treated stored roots. Untreated roots had substantial losses due to rotting (minimum 15%) after only one week, whereas treated roots of all cultivars were below 4%. This difference was even more marked after two weeks. There were no significant changes in DM content over the two week storage period in treated roots. This experiment again demonstrates the practicality of fresh cassava root storage in tropical lowland humid climates with minimal losses and maintenance of root dry matter content.

Popayan

Two storage experiments were carried out using cultivars adapted to the cold, high altitude conditions of this site (mean temp. 18°C, altitude 1,800 msl). In both trials, roots were stored in 1,5 and 20 kg bags, both treated and untreated with Mertect, for 1 and 2 weeks after harvest. The results obtained (Table 4) were very different from the experiments in other regions. Treated roots had high losses due to microbial deterioration after only one week, whereas untreated roots had lower losses. The deterioration was of bacterial, rather than fungal, origin. The low ambient temperatures were probably insufficient for the bag microclimate to reach the high temperatures (30-40° C) required for root curing. Thus, damaged tissues remained unrepaired and susceptible to pathogen invasion. The Mertect treatment, which increases the humidity of the root exterior, may facilitate this invasion. Mertect, itself, is not effective against most bacteria.

Thus, this cold climate extreme of cassava cultivation presents a very different picture from the other areas where storage trials were carried out. The combination of slow curing and bacterial invasion will require a different approach. Samples of bacterially-infected roots have shown that Erwinia is one of the principal pathogens. Control measures are currently being investigated.

Results of thiabendazole residue analysis.

Although Mertect, the thiabendazole-based fungicide used successfully in these root storage treatments, is considered relatively inocuous as a post-harvest treatment of vegetable produce (bananas and potatoes are presently treated commercially), it was thought necessary to determine the degree of penetration of the compound in root tissues after treatment. Given the thick peel layer of cassava, which is discarded on food preparation, the penetration of thiabendazole should be less than occurs in potato, for example.

Analyses of thiabendazole residues were undertaken by the TDRI, London following root shipment from CIAT and treatment at TDRI labs so that a zero time estimate could be obtained. The peel and parenchyma were analyzed separately. Results (Table 5) showed that while the peel contained substantial amounts of thiabendazole, as expected, the parenchyma (edible portion) of the root contained 1 mg/kg of residues, regardless of storage time prior to analysis. The levels of thiabendazole permitted in foods vary between countries but 5 mg/kg is considered a maximum safe level in potatoes. Thus, the raw root tissues have thiabendazole levels well below the maximum. These levels can be expected to decrease further on cooking.

Stored Root Quality

Although objective quality evaluations of stored roots have consistently shown that changes in root dry matter and starch content during storage are non-significant and that only minor sugar content increases occur, nevertheless a necessary preliminary was an evaluation of root quality by urban cassava consumers prior to commencing any marketing trials of the stored roots. Evaluations were, therefore, carried out using Cali and Palmira residents among CIAT employees. Each evaluation was designed in the following manner:

Roots stored for one or two weeks were compared with fresh roots of the same cultivar from the same field plot in each test.

Roots were evaluated in three states: (a) whole, uncooked; (b) peeled, sectioned as for cooking, but uncooked; (c) peeled, sectioned as for cooking, but cooked (boiled). (a) and (b) were visual and olfactory evaluations only while (c) also included taste/texture evaluations.

Samples were presented at random to panelists. Although no taste lab exists at CIAT, a nutrition lab was adapted to separate the panelists and to provide a secluded environment for the test. Twenty people were tested per session. The results of four separate evaluations are shown in Table 6 in which two cultivars, CMC 40 and M Col 22 were each evaluated after one and

two weeks of storage and compared each time with fresh roots of the same cultivar. The main conclusions were :

(1) Whole, stored roots were consistently evaluated as being less acceptable than fresh roots as regards their external appearance. This is unavoidable, since some drying out or discoloration of the cut tissues at the root ends is certain to occur. Even so, stored roots were evaluated in general as "normal".

(2) Peeled, sectioned uncooked roots were evaluated similarly, whether fresh or stored. Thus, the visible differences between the whole fresh and stored roots are not maintained after peeling.

(3) Cooked samples of fresh and stored roots were found to be very similar. The only difference was the sweeter taste of the stored roots. However, this difference did not cause stored roots to be marked badly on the taste evaluation, suggesting that at least some of these consumers like sweeter tasting roots.

The overall conclusion is that the consumers tested thought fresh and stored roots of the same cultivar were basically similar, although stored roots did taste somewhat sweeter and had a less acceptable external appearance.

Respiration Studies On Stored Roots.

Given the importance of maintaining root quality during storage and the potentially large losses in digestible carbohydrates, experiments were conducted on root respiration levels to determine if losses of starch and dry matter content due to respiration were maintained at a low, constant level during storage. Respiration studies were carried out at CIAT in a cooperative study with TDRI, London using roots of M Col 22 stored with the following treatments: ambient (25°C, 60% RH); plastic bag and plastic bag + Mertect treatment of roots. The respiration rate was determined at 0, 1, 2, 3, 6, 8 and 10 days after harvest (Figure 1).

Fresh roots had respiration (on a dry matter basis) of approximately 2-4 mg CO_2 g^{-1} day^{-1}. Ambient stored roots increased to a mean of 7.5 mg CO_2 g^{-1} day^{-1} within one day, reaching a maximum of 9.7 mg CO_2 g^{-1} day^{-1} by the third day. These latter high rates are equivalent to substantial losses of dry matter, 0.7% per day. Roots stored in plastic bags, with or without the Mertect treatment, maintained a low and constant rate of 3-4 mg CO_2 g^{-1} day^{-1}. Mertect-treated roots did, however, have slightly lower respiration rates than the untreated roots, probably due to the absence of fungal respiration. The differences in respiration rates between plastic bag and ambient-stored roots are due to the humidity differences: a high humidity environment which encourages wound healing (curing) permits a low respiration rate. A low humidity environment, which encourages the development of physiological deterioration, has a high respiration rate due to the metabolic activity of the deterioration process. Thus, plastic bag storage achieves the

aim of ensuring a low, constant respiration rate during storage. Further studies are planned to investigate the effects of cultivar, root damage and the storage environment.

Commercialization of Storage Technology.

Results of trials with the polyethylene bag and Mertect treatments have demonstrated that: (a) the method is successful over wide areas of the low and medium altitude tropics (1,500 msl); (b) it is simple, inexpensive and practical for farmers to adopt the method; and (c) consumer acceptability of the stored cooked roots is equivalent to that of the same roots when they are fresh.

However, for the commercial adoption of this technology the storage treatments must be integrated into the urban market chain for fresh cassava. This implies that intermediary and retail groups must also be involved in the adoption process. A project is currently under consideration in which the commercial adoption of storage technology will be attempted through the integration of farmer, intermediary and retail groups, with the added research objectives of root quality evaluation through consumer panels and an impact study to determine the size and distribution of the benefits of storage technology.

Root Quality Studies

During the numerous quality evaluations of stored roots, great variation in fresh root quality was frequently observed. Since the success of any root storage method ultimately depends upon the provision of high quality roots to the market, and since the causes of the variation found in fresh root quality were unknown, studies were initiated this to year resolve these uncertainties.

Previous CIAT research has shown that a correlation exists between root dry matter content and such quality factors as cooking time, root hardness and root durability among four promising cultivars examined at four ages. A CIAT-based study was thus initiated to test a broader range of cultivars and parameters to be calculated.

Twenty clones were, therefore, harvested at 7, 9 and 11 months from the same field plots at CIAT. Each clone was evaluated for several subjective quality factors (cooking time, taste, texture, etc.) and a range of objective chemical analyses were performed (starch, sugar, dry matter and high cyanide (HCN) contents).

Table 7 shows the mean values of each parameter at each harvest. Generally, the nine month harvest produced the best results, with roots having, on the average, better taste/texture evaluations and higher dry matter/starch contents than at the 7 and 11 month harvests. The total root cyanide (HCN) content was, in many clones, very high (M Ven 25 exceeded 2000 ppm) but tended to decrease with plant age. Cooking time tended to increase with plant age. Root hardness (as measured in mm by a penetrometer) did not change during the harvests. The percentage deterioration, an inverse measure of root durability (see Cassava Annual Report, 1979) was highest at the nine month harvest when root dry matter content was also at a maximum.

These general results do, however, conceal substantial variation within individual clones over harvest age. As an example, Table 8 presents the results for cooking time and taste/texture evaluations for each clone independently (space limitations preclude complete presentation of results for each variable separately). The cooking time of some varieties tended to increase with plant age. (e.g. M Ven 25, M Bra 12) while others decreased (M Col 22, CM 922-2). Generally, roots cooking in times exceeding 35 minutes were evaluated poorly for taste and texture, while roots cooking in less than 30 minutes were evaluated well. Overall the best cultivars were M Per 245, CM 91-3 and CM 523-7, all of which had excellent taste/texture evaluations and cooking times of 30 minutes or less.

Table 9 shows the correlations between the various root parameters. These tend to fall into two groups of significant correlations:

(a) Those between the various related chemical characters eg. total and free HCN content; total and reducing sugar content; starch and sugar content. The dry matter-starch correlation was not as consistent as expected, only appearing at the first harvest. The specific gravity method of dry matter/starch estimation consistently underestimated the dry matter and starch content as determined by oven drying and chemical analysis, respectively.

(b) Those between the various subjective evaluations eg. cooking time and flavor, flavor and texture, cooking time and texture.

There were few consistent correlations between the chemical and subjectively evaluated parameters: only bitterness and total root HCN content were significantly correlated. Root dry matter content did correlate with raw root hardness as measured by a penetrometer.

This experiment demonstrates the poorly understood nature of these root quality factors and the importance of gathering more extensive data on quality changes in differing sites and climatic regimes with the dual aim of improving the reliability of obtaining good quality roots in the market place, fresh or stored, and of aiding the breeding program in the evaluation of promising lines for human consumption. Next year further studies on fresh root quality are planned, with the possible inclusion of amylose content determinations as an aid to evaluating starch quality and cooking characteristics.

(b) Cassava Drying

The work on cassava drying has continued in the two areas mentioned in the 1983 Cassava Annual Report, namely:

(1) The commercial operation of the seven natural drying plants on the Atlantic Coast of Colombia.
(2) The development and evaluation of a through circulation drier for cassava chips.

During 1984 research has also been initiated on a cooperative project between CIAT, The Instituto de Investigaciones Tecnologicas, (IIT), and the Universidad del Valle, Univalle, on the production of cassava flour for human consumption. This project is partially financed by the International Development Research Center, IDRC.

Commercial operation of the drying plants on the Atlantic Coast.

The production of dry cassava in the seven plants on a commercial scale during the 1983/84 season has permitted the collection of reliabe technical and economic data on their operation. These studies were partially financed by the Colombian Rural Integrated Development Program (DRI).

Between November 1983 and June 1984, with a total of 4,000 m^2 of drying floor, 2,395 t of fresh cassava were processed to produce 946 t of dry cassava, giving a conversion ratio of 2.53 t of fresh cassava to produce one ton of dry cassava. The average moisture content of the dry cassava, as determined by the feed concentrate manufacturer, was 12.7%, well within the quality standard of 14%.

The results of the operation of the pilot plant in 1982 and 83 indicated that under the climatic conditions prevailing on the Atlantic Coast a batch of fresh cassava chips loaded at 12 kg per square meter of drying floor take 30 to 40 continuous hours to dry (18 to 28 daylight hours). Consequently, a natural drying plant operating six days a week should process three batches per week and a total of 60 batches per year, assuming that the dry season lasts for 20 weeks. During the 1983/84 season, the seven plants operated with average loading rates of 12.3 kg/m^2 and processed 84% of the theoretical number of batches possible, to give an 86% occupation of total plant capacity. The operation at below full capacity was due principally to poor weather conditions in certain areas during part of the season and mechanical breakdowns of the gasoline motors which drive the chipping machines (see below).

In general, the drying technology employed has proved to be quickly adopted and easily managed by the farmers. The only element that has caused problems has been the 5 hp gasoline motor which, under continual use, has not proved to be sufficiently powerful or structurally strong enough. In five of the seven plants these motors had to be replaced by 8 or 10 hp motors, which have subsequently operated without further problems. The design of the Thai type chipping machine itself has been slightly modified to make it more rigid and to permit easier alignment and tensioning of the drive belts. The direction of rotation of the

cutting disc has also been reversed to allow for tractor PTO drive in addition to the use of gasoline or electric motors.

The average price paid for fresh cassava roots was Col $4,980/t and the average selling price of one ton of dry chips was Col $18,460.oo. With an average conversion rate of 2.53 and processing costs amounting to Col $5,120 per ton of dry cassava, the process gave a net profit of Col$ 740 per ton of dry cassava (Table 10).

These results show that natural drying of cassava on the Atlantic Coast of Colombia is a technically feasible and an economically profitable activity. With the experience gained during this first year of commercial operation, the drying plants should turn into a considerable source of income for the members of the farmers associations, not only through profit distribution but also through payment for working in the plants and through the possibility of increasing cassava production. For the 1984/85 season a further 13 plants are under construction, taking the total number of plants to 20 with an estimated capacity to produce 4,250 t of dry cassava/per year

Development and evaluation of a through circulation drier.

To obtain more accurate operating cost data on drying cassava chips in a through circulation drier coupled to a flat plate solar air heater, a pilot plant was constructed at Montanita Farm, Betulia, Sucre based on the design parameters obtained during the experimental trials undertaken in previous years at CIAT.

The drying system (Figure 2) consists of a 6 m drying bin, a centrifugal fan and a 30 m. solar collector. The fan is driven by a 3 hp gasoline motor at 1800 rpm to deliver 100 m^3/min of air against a head of 1.5" w.g.

The drying system was evaluated for a period of two months, from the February 18th - April 20, 1984.

Solar collector performance.

Operating daily from 0700 to 1900 hours with an airflow of 106 m/min, the solar collector raised the average ambient air temperature by 5 ^oC, from 30.7 ^oC to 35.7 ^oC, and reduced the relative humidity from 61.8% to 46.0% (Table 11). The collector efficiency was 63%, a level considered normal for this type of collector given the high airflow and low temperature increment.

Drier capacity.

The optimum loading density (kg of fresh cassava chips per square meter of drying surface) of the drier was found to be 150 kg/m^2. At this load, average drying times were 24 net hours or the equivalent of two days (drying starting at 07.00 and finishing at 19:00 hours the following day). Under the climatic conditions prevailing in Betulia the drier gave a 20% increase in capacity compared with the experimental drier at CIAT.

Combined natural and through circulation drying.

A possible method for increasing the capacity of the drying plants is through the partial drying of the cassava chips on the concrete drying floor for one day, followed by through circulation drying in bins. Trials were therefore carried out to determine the relationship between concrete floor drying area and bin area to achieve total net drying times of 24 hours (two days), Table 12.

Using a fixed loading rate of 8 kg/m^2 on the concrete floor, the total quantity of fresh cassava chipped was increased from 800 to 1600 kg. After 12 hours natural drying on the concrete floor the semi-dry chips had attained a moisture content of between 24 and 39%. Subsequently, on loading the semi-dry chips into the drying bin, a further 7 to 17 hours were required to complete the drying process. The three replications using 1600 kg fresh cassava show that with this quantity it is possible to complete drying within the 24 hours. It can therefore be inferred that to establish a combined drying system of this nature, 200 m^2 of concrete floor will require 6 m^2 of drying bin.

Investment cost of the drying systems

The construction cost of the drying system is shown in Table 13. The most costly component is the fan and motor, followed by the solar collector and the drying bin. It is important to note that in the case of the solar collector, 70% of the cost is made up of the foundations, walls and wooden frames that serve to support the collector material (galvanized iron sheets) and the polyethylene cover which make up the other 30% of the cost. Since the drying plant will require a roof to cover the product storage area, the chipping machine and the drying bins, in future designs it would seem sensible to incorporate the solar air heater into the roof area and thereby substantially reduce the construction costs of this item.

Although scaling up for greater drying capacity will result in lower unit costs of construction, these figures have been used to estimate and compare the investment costs of concrete floor drying, bin drying alone and combined natural and bin drying (Table 14). The production of one ton of dry cassava chips using the bin drier /solar collector system would require over four times the investment compared with concrete floor drying alone. However, the difference is reduced to only 1.7 times when comparing concrete floor drying with combined natural and bin drying. This suggests that the latter system could offer advantages over concrete floor drying alone by reducing the total area required for drying (187.5 m^2 against 315 m^2).

Furthermore, better use could be made of the combined system by placing the successive layers of semi-dry cassava chips on top of the previous layer of dry chips in the drying bin. This would obviate the need to ensure that the moisture content of each day's batch is reduced to below 14% (say in the event of poor ambient weather conditions) and allow the drying bin to be used as a temporary store with bagging off taking place once a week.

Operating costs

An estimate was made of the labor requirement and the operating cost of the motor (gasoline and oil consumption) for both bin drying alone and combined natural and bin drying, Table 15 . Both systems required the use of substantially more labor than concrete floor drying. With bin drying it was found necessary to turn the chips every two hours to ensure even drying and prevent deterioration of the upper layers and this operation proved to require more time than for turning the same quantity of chips on a concrete floor. Combined natural and bin drying is inherently more labor intensive since the chips have to be handled twice, however in this system the turning of the semi-dry chips in the bin is avoided. The operating cost of the gasoline motor was very high and the use of this type of motor is obviously uneconomic. Future trials will be carried out using an electric motor.

Future work with the solar collector

During the 1985 drying season on the Atlantic Coast, further trials will be carried out on combined natural and bin drying to obtain better operating cost estimates. The solar collector will be adapted, removing the polyethylene cover, to simulate solar radiation collection from roof areas.

Evaluation of an indirect coal-fired burner

Coal in Colombia is an abundant and relatively cheap source of energy and so it was therefore decided to design and evaluate at CIAT a simple indirect coal-fired burner. The drying system employed was similar to the one described in the 1982 Cassava Annual Report.

The burner (Figure 3) consists of two parts: the combustion chamber and the heat exchanger. The combustion chamber, constructed of Concrax, a refractery material, is cyelindrical with a volume of 0.16 m^3. The 1.13 m long and 0.43 m diameter single tube heat exchanger is supported on top of the combustion chamber. The tube, 0.19 m in diameter, has 20 interior and 40 exterior fins. The combustion gases flow vertically upwards through the heat exchanger tube and exhaust to the atmosphere through the chimney. Ambient air enters at the top of the heat exchanger and is drawn down through the shell and around the outside of the combustion chamber. A centrifugal fan (Dayton 30073) placed at the exit of the burner, blows the hot air through the product which is supported on the false floor of a 2 m^2 drying bin, Figure 4.

For the drying trials the air was maintained at a temperature of 55°C. This temperature was achieved approximately two hours after lighting the burner with a charge of 15 kg of coal and was subsequently maintained by charging 5 kg of coal every hour.

The ambient air temperature was 24°C. The airflow was held constant at 38 m^3 /min and the pressure drop through the system was 2" w.g. The burner delivered 19,800 k cal/h with an efficiency of 53%.

Table 16 shows the results of the trials undertaken to determine the variation in drying time and coal consumption with increasing drier loading. Coal consumption decreases with drier loading. However, with loadings greater than 250 kg/m^2 turning the chips during drying becomes

impractical. This is, therefore, the upper loading limit to maintain product quality. Since the rate of decrease in coal consumption is not as great at the higher loadings, the selection of an optimum loading rate will probably depend more on shift hours than on fuel cost.

Artificial drying systems based on coal will be thermally more efficient if they are operated continuously thereby avoiding letting down the burner each day. However, this will require at least one operator tending the burner throughout the night. Drying trials are continuing to determine the most convenient mode of continuous operation and to determine whether it is possible to avoid turning the cassava chips using a double bin reversible airflow arrangement in which air is forced first up and then down through the product.

Joint CIAT/IIT/UNIVALLE Wheat/Cassava Composite Flour Project

The objective of this project is to determine the technical and economic conditions required for the development of a rural cassava flour industry in Colombia. The aim is to design and implement a viable system for the production and use of cassava flour in bakery products, Figure 5 . The project got underway in the second semester of 1984 and the experimental phase, partially financed by IDRC, will continue for two years. A further semi-commercial or development phase may then be undertaken according to the results achieved in the experimental phase.

The principal problems to be tackled to achieve the above objective are: (1) the introduction of improved cassava production technology to reduce costs and raw material prices; (2) the development of an appropiate cassava processing technology to produce a high quality flour at a competitive price; (3) the determination of mechanisms to motivate the wheat miller to produce and the baker to use composite flour; (4) the optimization of baking procedures for the use of the flour; and (5) the evaluation of consumer preferences for and acceptance of composite flour products.

The methodological framework that has been developed to carry out these activities is shown in Figure 6 . The project is divided into three basic research areas: economic evaluation, design and development of processing plant and bakery product development. In the first year the economic evaluation, which will be carried out jointly by the Economics Section of the Cassava Program and IIT, includes individual studies to obtain more detailed information on the Colombian wheat market, cassava production zones, the wheat milling industry, the bakery industry and consumer habits and preferences with regard to bakery products. This information will orient subsequent work on flour processing and bakery product development and a decision will be made as to the most appropiate cassava production region for the establishment of the flour industry.

The design and development of processing plant will be carried out by Univalle and the Utilization Section of the Cassava Program to achieve, after the first year, the construction of a pilot plant to produce cassava flour. Also during the first year, IIT will carry out bakery trials to determine the optimum levels of cassava flour substitution, the need for fortification with soybean flour to maintain

the nutritional quality of the products and the changes in bakery procedures required when using wheat/cassava composite flours. An important part of this work will be to determine whether cassava variety and plant age affect bakery product quality.

In the second year of the project, seven tons of composite wheat/cassava flour will be produced in a wheat mill identified in the selected region so as to test both baker and consumer acceptance of the flour and bakery products. The results of these studies, together with the price and cost information obtained from the pilot processing plant and trials to be conducted on farms in the selected region, will be used to prepare a feasibility study with recommendations as to the actions necessary to establish the use of wheat/cassava composite flours in Colombia.

Table 1. Results of two storage experiments on the north coast of Colombia.

	ONE WEEK STORAGE				TWO WEEK STORAGE			
	+ MERTECT		- MERTECT		+ MERTECT		- MERTECT	
	Microbial growth	Rotting	Microbial growth	Rotting	Microbial growth	Rotting	Microbial growth	Rotting
	A. Betulia, Sucre: storage in an open site protected from sun and rain							
Bag size (kg)								
20	4	4	16	9	15	5	22	21
5	* [a]	1	14	8	15	5	33	23
1	1	2	8	3	3	3	12	4
	B. La Pena, Atlantico: storage in an enclosed environment.							
20	28	28	32	31	– [b]	–	–	–
5	9	7	42	28	20	11	74	68
1	3	3	8	3	6	6	15	10

[a] Trace only

[b] Roots completely rotted due to storage in excessive temperatures.

Table 2. Fungicide treatment referred to in Table 1: comparison of Mertect treated vs. untreated roots for both microbial growth and rotting evaluations.

	External microbial growth %	Internal rotting %
Treated roots	8[a*]	4[a]
Untreated roots	21[b]	14[b]

* Numbers followed by a letter(s) in the same column are not significantly different at P = 0.001.

Table 3. Results of a storage experiment at Carimagua in which treated and untreated roots of three cassava cultivars were stored in 5 kg bags.

	Storage time			
	One week		Two weeks	
Treatment	Microbial growth[a]	Rotting[a]	Microbial growth[a]	Rotting[a]
M Pan 19				
+ Mertect	1	3	7	0
- Mertect	22	15	69	65
M Col 1916				
+ Mertect	9	4	14	10
- Mertect	36	17	60	68
M Ven 77				
+ Mertect	7	0	12	3
- Mertect	28	27	95	82

[a] Score of 0-100.

Table 4. Results of two storage experiments using Mertect-treated and untreated roots of two cassava cultivars stored for one and two weeks after harvest, Popayan, 1984.

Root treatment	Storage time (week)	Bag size (kg root/bag) 1 M.G.[a]	1 T.D.[b]	5 M.G.	5 T.D.	20 M.G.	20 T.D.
Experiment 1:	M Col 1522						
+ Mertect	1	0	40	8	30	1	30
	2	0	26	14	36	6	31
- Mertect	1	3	24	8	8	17	9
	2	7	28	18	14	39	7
Experiment 2:	Regional amarilla						
+ Mertect	1	2	24	5	12	6	20
	2	7	57	16	34	24	4
- Mertect	1	3	10	25	22	19	18
	2	7	17	24	28	35	33

[a] M.G.: External microbial growth evaluation.

[b] T.D.: Total deterioration evaluation. (microbial rotting + physiological deterioration).

Table 5. Thiabendazole residues in the peel and parenchyma portions of stored roots.

Storage time (weeks)	mg thiabendazole/kg root tissue Peel	Parenchyma
0	77	0.2
1	84	0.9
2	103	0.9

Table 6. Results of consumer quality evaluations of three states of stored and fresh roots of M Col 22 and CMC 40.

	CMC 40				M Col 22			
	1 week		2 weeks		1 week		2 weeks	
	F[a]	S	F	S	F	S	F	S
Whole root								
General aspect	3.5[b]	2.8	4.2	3.0	4.0	3.2	3.5	2.4
Freshness	4.0	2.6	4.0	2.8	4.0	3.0	3.3	2.4
Peeled root								
General aspect	3.6	3.2	3.7	3.4	3.9	3.9	3.4	3.5
Smell	3.2	3.1	3.1	3.1	3.3	3.5	3.1	3.2
Color	3.8	3.2	3.5	3.3	3.9	3.9	3.1	3.1
Starch content	3.7	3.4	3.9	3.1	3.5	3.8	3.1	3.1
Freshness	4.0	3.4	3.8	3.6	3.6	3.9	3.4	3.8
Cooked root								
General aspect	4.1	3.2	3.9	3.3	3.5	3.8	4.0	3.5
Smell	3.8	3.3	4.3	3.1	3.4	3.5	3.4	3.4
Taste	4.0	3.1	3.9	3.4	3.8	3.7	3.8	3.5
Texture	3.4	3.3	3.2	3.0	3.2	3.3	3.5	3.4
Starch content	3.6	3.3	3.7	3.4	3.5	3.4	3.1	3.3
Sweetness	0.2	1.1	0.6	0.9	0.4	0.7	0.3	0.8

[a] F = freshly harvested roots; S = stored roots (1 or 2 weeks).

[b] For all characters evaluated on 0-5 scale: 0 = bad, 5 = excellent, with the exception of sweetness: 0 = not sweet, 5 = very sweet taste

Table 7. Mean values of twenty clones for variation in quality characteristics with plant age.

Parameters	Age at harvest (months)		
	7	9	11
Dry matter (specific gravity) (%)	31.5	34.3	31.1
Dry matter (oven drying) (%)	32.5	37.0	34.7
Starch (%)	81.3	85.3	86.9
Reducing sugars (%)	1.7	1.2	1.5
Total sugars (%)	3.1	2.7	4.6
HCN free (ppm)	28.5	28.5	28.2
HCN total (ppm)	557.5	319.8	281.2
Cooking time (min)	26.4	27.2	32.9
Flavor [a]	2.5	1.8	2.2
Texture[a]	1.8	1.4	1.6
Bitterness[a]	0.7	0.4	0.5
Hardness (penetrometer, mm)	2.2	2.0	2.1
Deterioration %	26.7	46.8	27.6

[a] Evaluation scales: 0 = excellent; 3 = bad.

Table 8. Results of cooking time and taste/texture evaluations of twenty clones at 7, 9, and 11 months.

	7 months		9 months		11 months	
	Cooking time	Taste/ texture	Cooking time	Taste/ texture	Cooking time	Taste/ texture
M Ven 25	40[a]	4[b]	40	2	35	4
M Per 245	11	0	20	0	20	0
HMC-1	15	2	20	0	34	0
M Cub 47	15	2	30	2	35	2
M Col 2059	28	2	20	0	27	0
M Col 1522	36	4	20	2	31	2
M Col 1468	16	2	19	0	32	1
M Col 22	34	2	18	0	25	0
M Bra 12	34	4	37	4	35	4
CM 1585-13	25	0	25	0	40	2
CM 1559-5	18	1	30	0	38	1
CM 1223-1	40	4	40	4	37	2
CM 981-8	40	4	38	4	40	4
CM 922-2	40	4	40	1	27	2
CM 849-1	31	4	33	4	40	4
CM 681-2	40	4	29	2	36	4
CM 523-7	15	0	20	0	20	0
CM 507-37	15	2	23	0	35	2
CM 489-1	20	2	23	0	40	2
CM 91-3	15	0	20	0	30	0

[a] Cooking time expressed in minutes; if not cooked by 40 minutes considered as hard texture.

[b] Scale of 0 to 4 in which: 0 = excellent; 4 = bad, sum of independent taste and texture evaluations.

TABLE 9. **Significant Correlations Between Root Quality Characters in each of Three Harvest**

	Dry Matter	Starch	Sugar Red	Sugar Total	HCN Free	HCN Total	Cooking Time	Flavor	Texture	Bitterness	Hardness	Deterioration %
Dry Matter		+ a)	–	–							–––	++
Starch			–––	––							–	+
Sugar (reducing)				+++	––			–			+	
Sugar (total)											+	–
HCN Free						+++				+		
HCN (Total)							+	+		+++		+
Cooking Time								+++	++			
Flavor									+++	++		
Texture												
Bitterness											+	–
Hardness												–
Deterioration %												

a) + = positive correlation; – = negative correlation; one + or – per harvest where significant at $P < 0.05$ or higher.

TABLE 10. Operating costs of a cassava natural drying plant. Average values for the seven plants in Colombian pesos/t of dry cassava.

	Col $	%	Col $
Variable costs			15,500
Raw Material	12,600	71.1	
Fuel	60	0.3	
Labor	930	5.2	
Transport	1,280	7.2	
Other costs[a]	630	3.6	
Fixed costs			2,220
Management[b]	660	3.7	
Depreciation	300	1.7	
Interest (21%)[c]	1,260	7.1	
Total			17,720
Selling price			18,460
Profit			740

[a] Other costs include bank charges etc.

[b] Management includes maintenance and administration

[c] Interest on investment and working capital

Table 11. Performance of 30 m^2 solar collector for an average of 43 observations from 0700 to 1900.

Ambient conditions			Drying air conditions			Collector performance		
Temp. °C	Relative humidity %	Radiation cal/cm^2.min	Airflow m^3/min	Temp. °C	Relative humidity %	Temp. increment T° C	Relative humid decrement RH %	Efficiency %
30.7	61.8	0.62	106	35.7	46.0	5.0	15.8	63

Table 12. Combined natural and through circulation drying.

Concrete floor drying (8 kg/m^2)									
	Fresh chips		Semi-dry chips		Through circulation drying			Ambient conditions	
Area of concrete floor used m^2	Weight kg	Moisture content % b.h[a]	Weight kg	Moisture content % b.h.	Drier loading kg/m^2	Drying time h	Total net drying time h	VPD[b] mm.Hg	Radiation Cal/cm^2.min
100	800	71	318	27	53	8	20	13	0.67
125	1000	62	527	28	88	7	19	14	0.77
150	1200	65	576	28	96	7	19	12	0.76
175	1400	69	648	33	108	7	19	15	0.78
200	1600	68	839	39	140	17	29	12	0.58
200	1600	64	789	27	131	8	20	19	1.02
200	1600	62	800	24	133	8	20	16	0.85

[a] % moisture content on a wet basis.

[b] VPD; vapor pressure deficit

Table 13. Investments costs of the through circulation drying system with solar collector, June 1983[a]

Component	Cost Col. $	Unit Cost Col. $/m^2
Drying bin, m^2	52,800	8,800
Solar collector, 30 m^2	77,900	2,597
Fan and motor	101,300	
TOTAL	232,000	

[a] US$ 1.00 = Col $ 80.oo.

Table 14. Investment cost comparison of three drying systems for cassava chips in Colombian pesos per ton of dry cassava.

Drying systems	Investment Col. $	Ratio
(1) Concrete floor (315 m^2)[a]	157,500	1.0
(2) Bin drier (17 m^2) plus solar collector (85 m^2)[b]	644,700	4.1
(3) Concrete floor (157.5)[a] combined with bin drier (5 m^2) plus solar collector (25 m^2)[b]	259,700	1.7

[a] Loading at 8 kg/m^2, at a cost of $500/m^2.

[b] Costs estimated from data in Table 13.

Table 15. Operating cost comparison of three drying systems for cassava chips.

Drying system	Labor man-hours[a]	Fuel cost[a] Col $
Concrete floor	10.5	-
Bin drier/solar collector	16.0	2,000
Combined natural and bin drier/solar collector	15.0	1,200

[a] Per ton of dry cassava

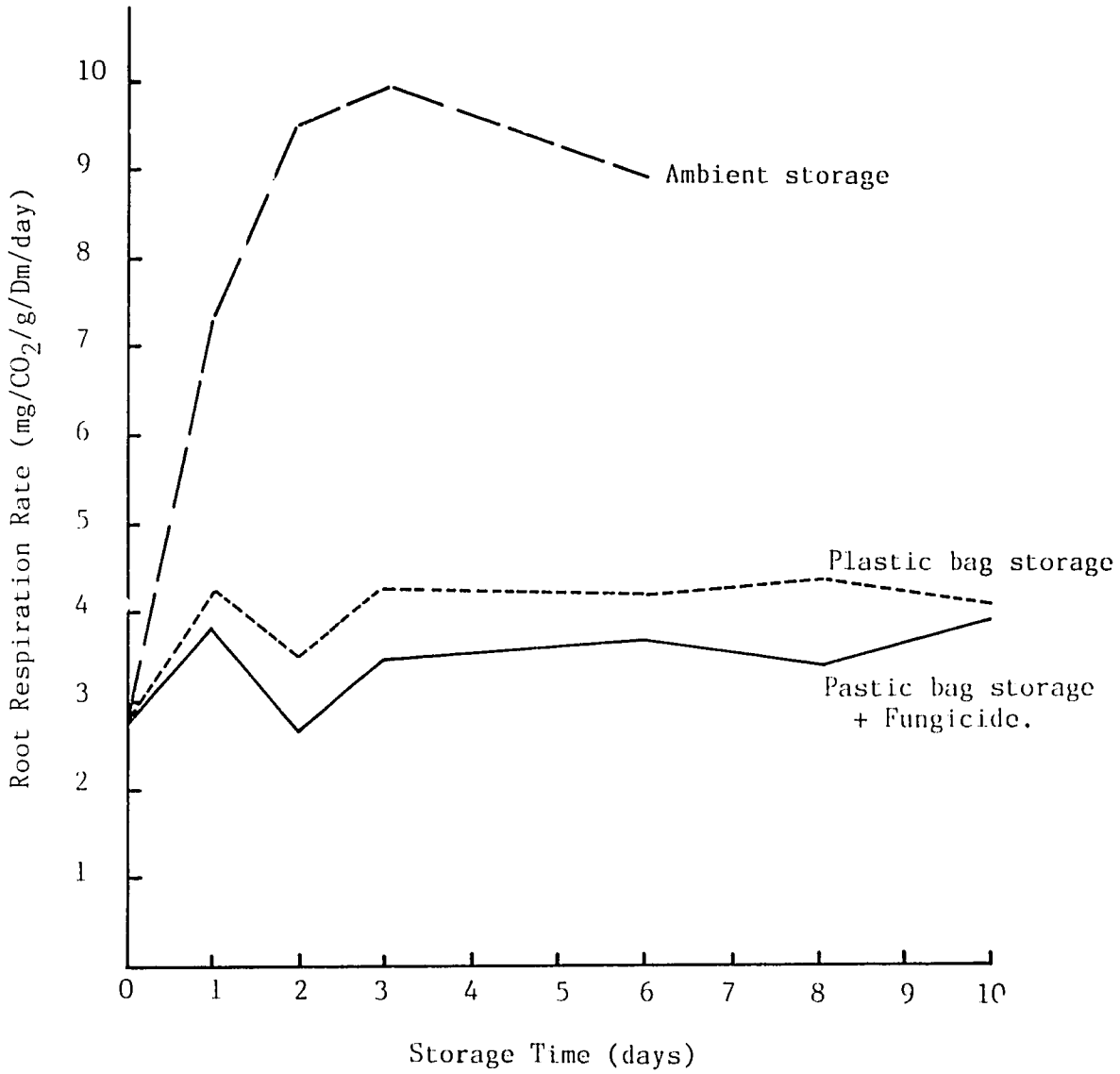
Table 16. Through circulation bin drying of cassava chips using coal as the heat source at an initial cassava moisture content of 62% and air drying temperature of 55°C.

Drier loading kg/m^2 [a]	Airflow m^3/min.t	Drying time h[b]	Coal consumption kg coal/kg dry cassava
50 (2)	370	4.7	0.60
100 (2)	180	7.0	0.51
150 (4)	120	9.0	0.47
175 (2)	100	12.3	0.43
200 (4)	90	13.0	0.41
250 (2)	70	17.3	0.40

[a] Figures in parentheses indicate the number of replications per trial.

[b] Starting cold, approximately two hours were required to reach the mean drying temperature of 55°C.

Figure 1. Cassava Root Respiration in Different Storage Environments



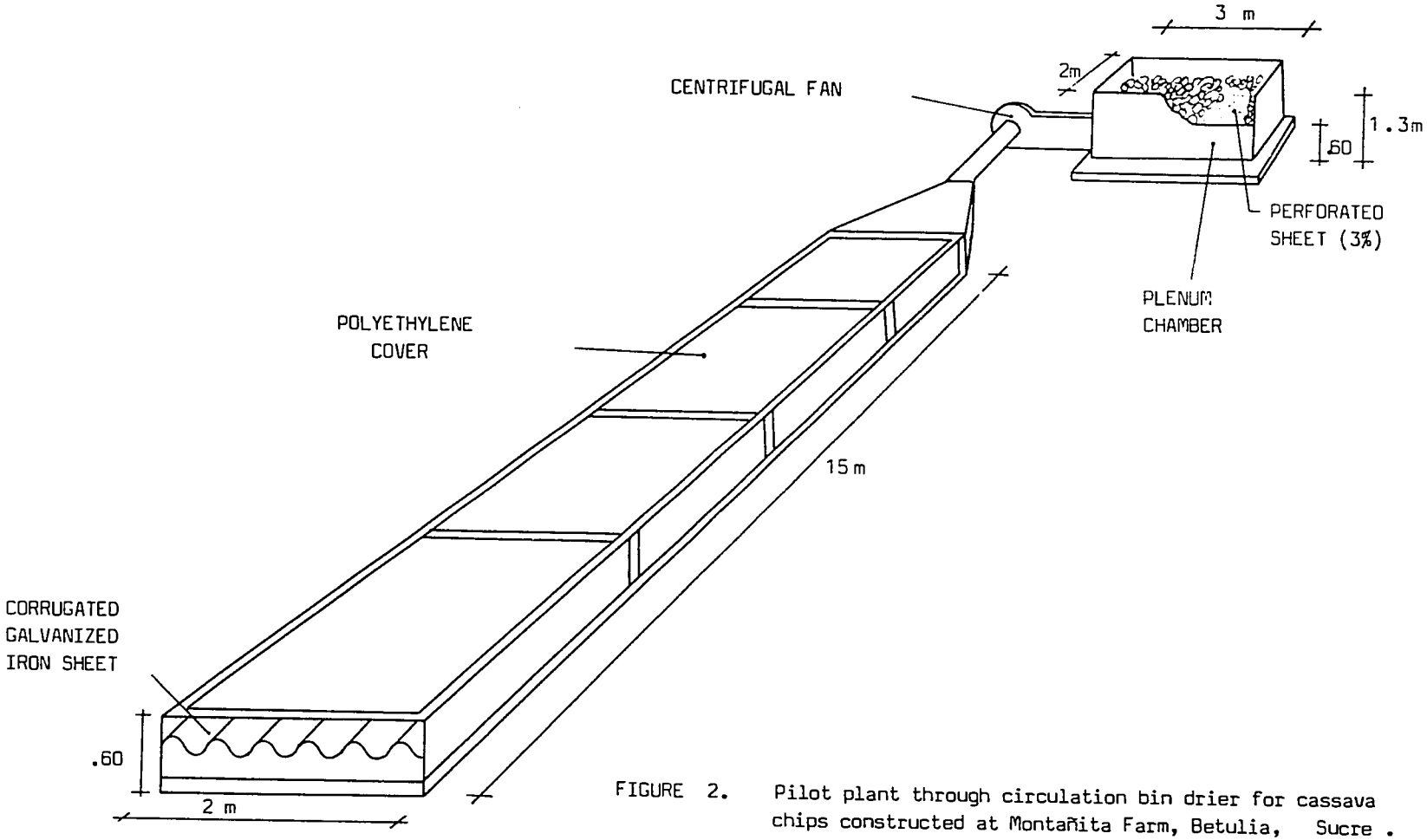


FIGURE 2. Pilot plant through circulation bin drier for cassava chips constructed at Montañita Farm, Betulia, Sucre .

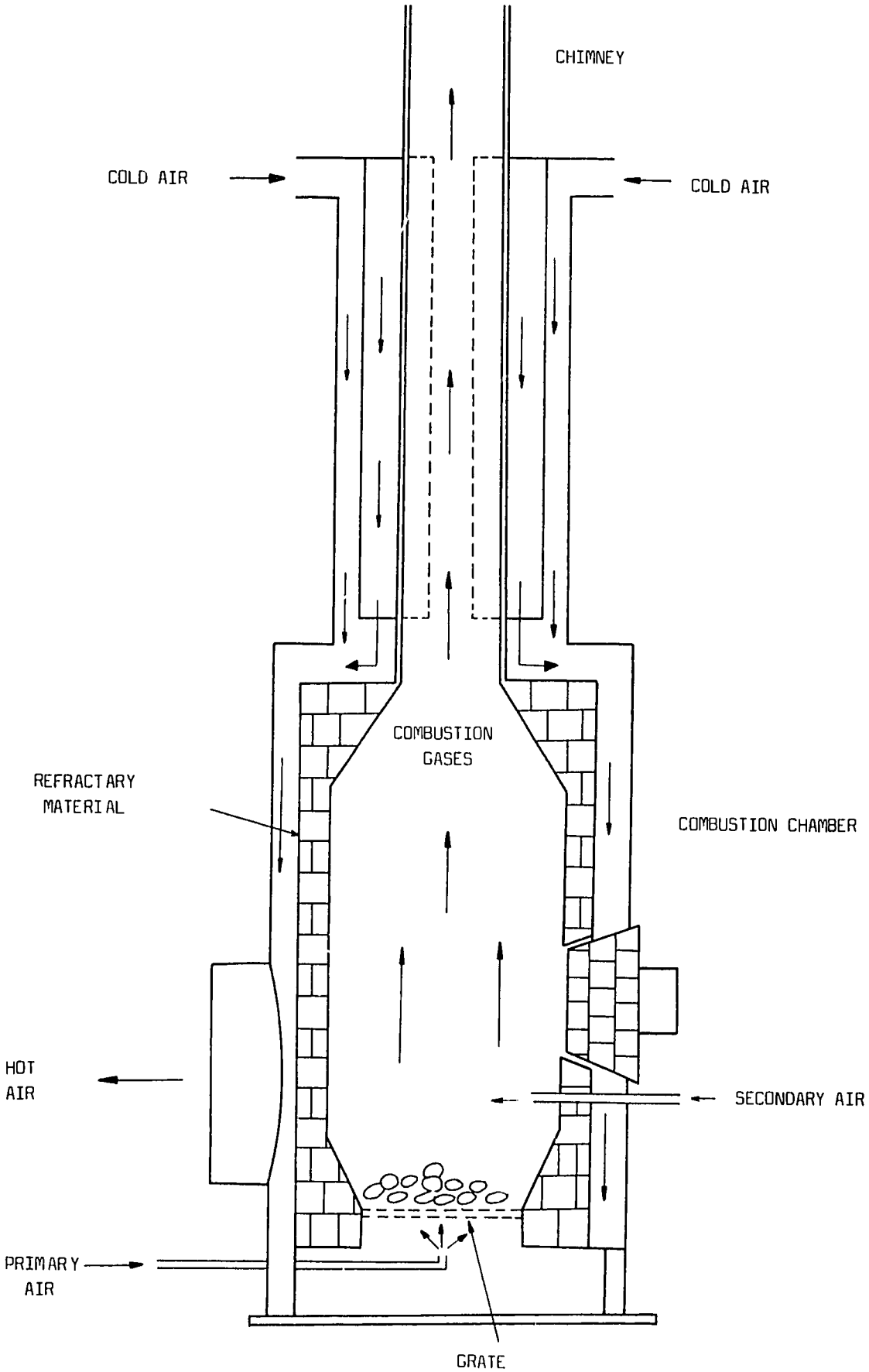


FIGURE 3. SECTION OF THE INDIRECT COAL FIRED BURNER

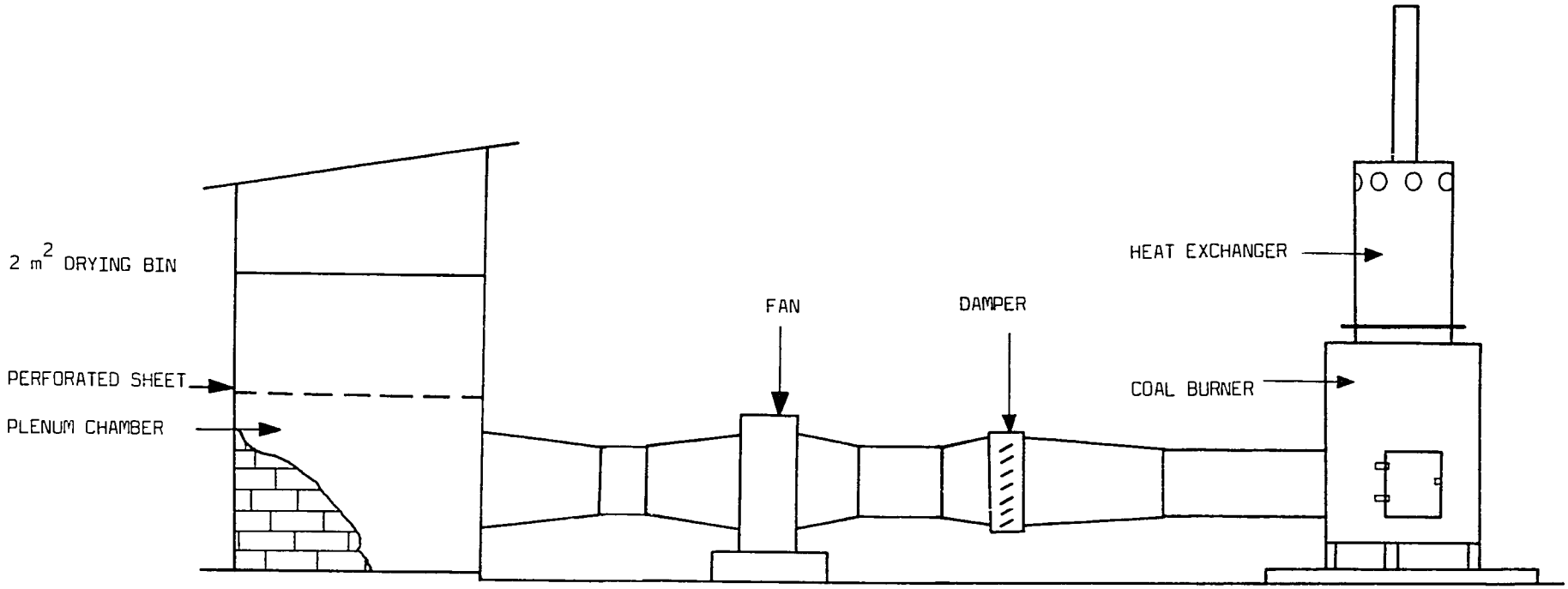


FIGURE 4. DIAGRAM OF THE EXPERIMENTAL THROUGH CIRCULATION DRYING SYSTEM INCORPORATING AN INDIRECT COAL FIRED BURNER.

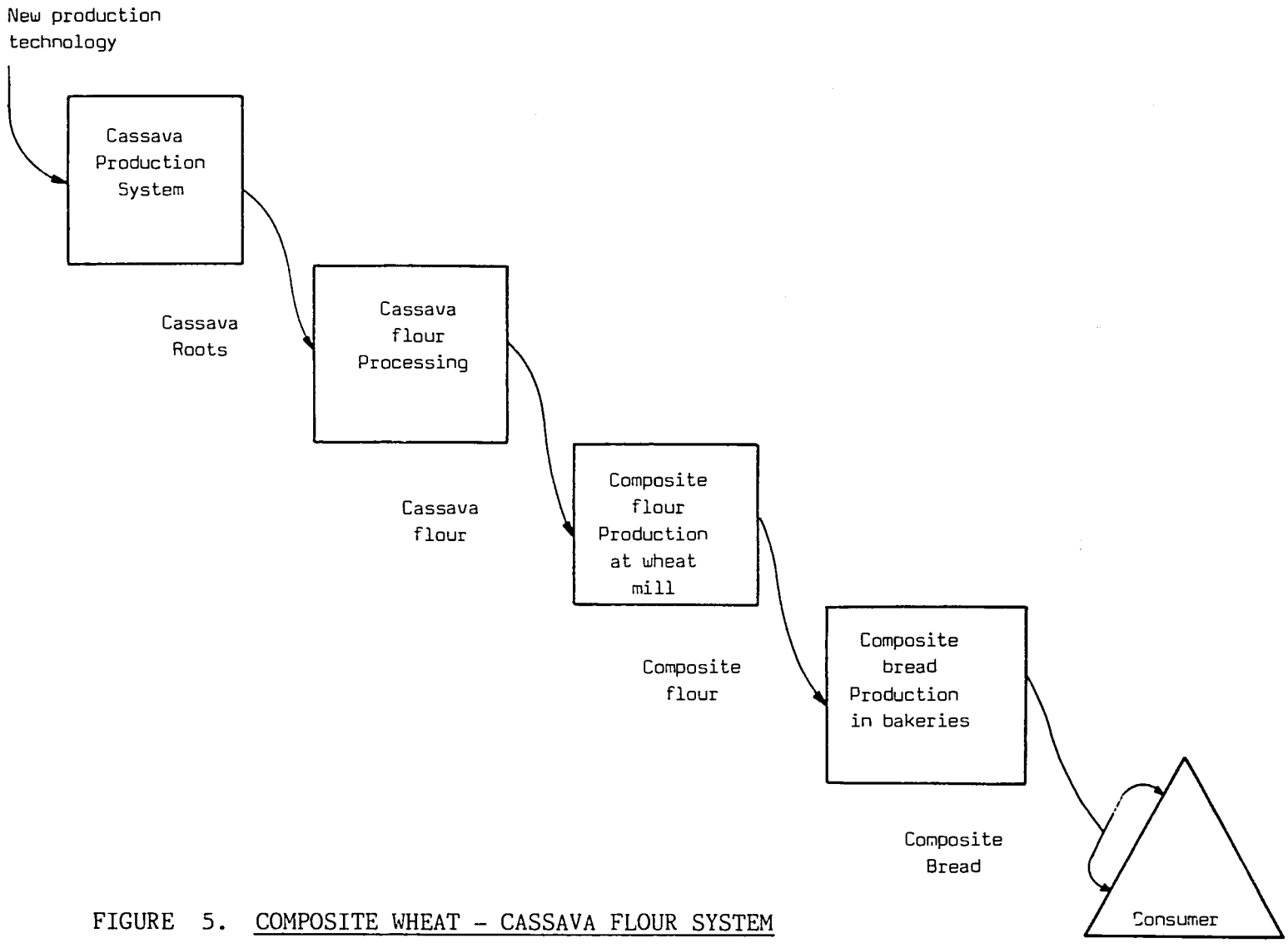
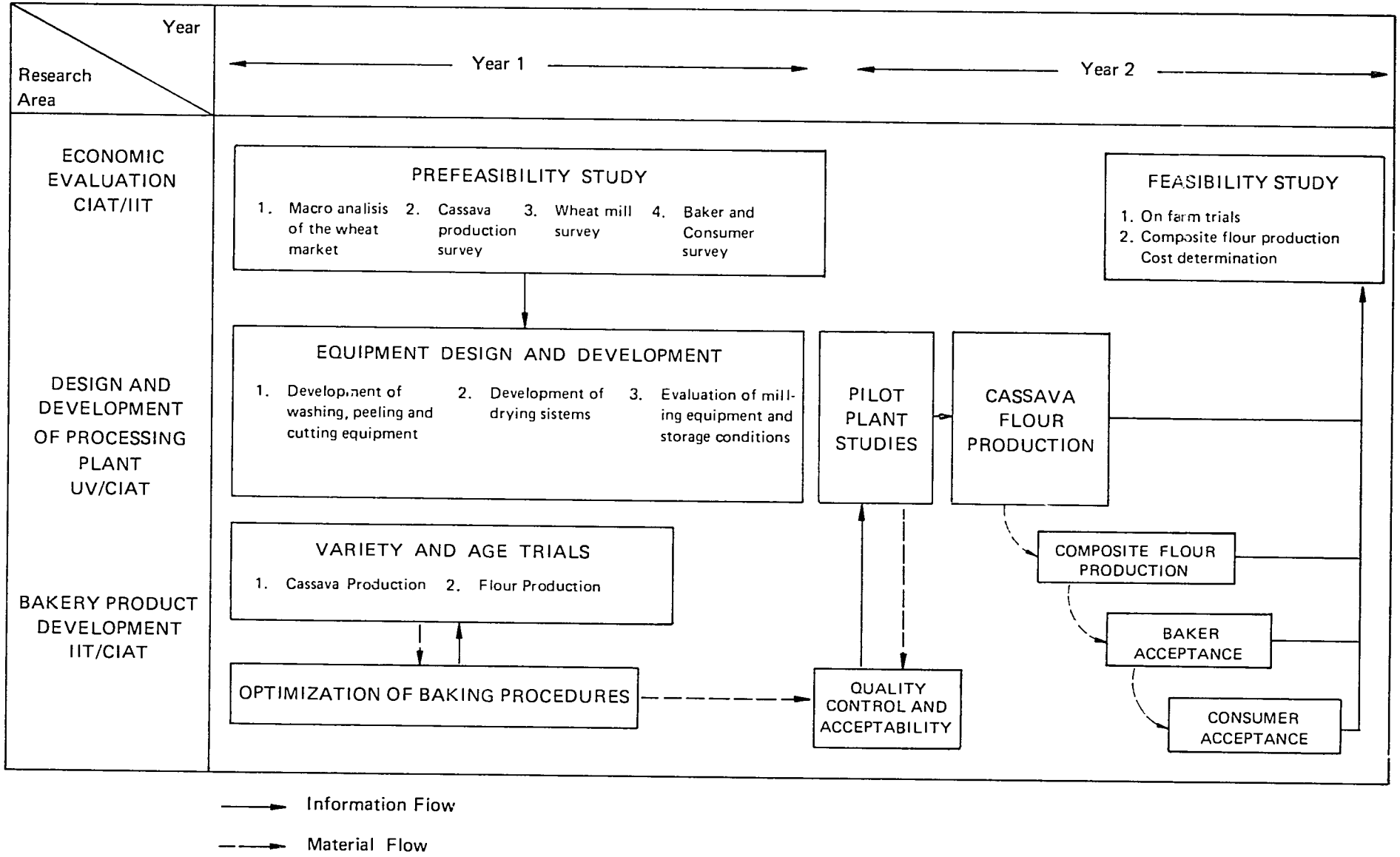


FIGURE 5. COMPOSITE WHEAT - CASSAVA FLOUR SYSTEM

FIGURE 6. **PRINCIPAL ACTIVITIES IN THE CASSAVA BAKING FLOUR PROJECT**



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1. Information Needs for Planning and Evaluation of Cassava Projects.

1.1 Introduction.

In last year's Cassava annual report a methodological framework was developed to assist in the planning of integrated cassava projects. The attention was focused on a managerial approach, describing the steps to initiate and carry out these projects. Important steps in their development were the design of a macro-planning frame, assessment of institutional capacity, project financing, phasing of activities in the project execution, support activities and the replication and monitoring of integrated projects.

This year's annual report will focus on the development of a framework for the systematic collection of information required to establish integrated projects. In addition, it will report on the progress in the collection and interpretation of this information.

The information obtained through integrated projects serves two basic purposes: (a) It supplies the data needed for successful implementation, management and development of integrated projects. A key step in this process is the screening of potential production zones for their appropriateness for integrated projects and the selection of end markets. This depends upon accurate information. (b) It provides the data to estimate the potential project impact and for evaluation of the success of the project later on.

Often, both purposes overlap considerably. For example, without the development of integrated projects the traditional and rather stable cassava markets will not normally stimulate the adoption of new production technology; as a result technology levels will remain low and inhibit cassava from playing a role in the new non-traditional markets which develop as urbanization occurs and GNP increases in Latin America. In these non-traditional markets the role of cassava can be increased as a food/feed calorie-source in Latin America and motivate the farmer to improve his present technology. The information on non-traditional potential end-markets for cassava will be of prime value for the successful management of integrated projects as well as for a detailed analysis of their possible impact on calorie availability. Similarly, the information on present technology at the farm level will provide a basis to estimate the effect of improved market access on stimulating adoption of improved technology while simultaneously providing the baseline from which the project impact can later be evaluated.

1.2 Description of the main study areas for planning and evaluation of integrated cassava projects.

The methodological framework of the information needs can most easily be conceived in a systems-framework (see Figure 1). Integrated cassava projects reinforce traditional and new or improved market outlets, through the combination of improved cassava production with new or improved cassava processing methods. These new cassava systems (Section 1, Figure 1) will, at least, initially exist in conjunction with the traditional cassava system; (2) present in a country and will

fulfill a particular role within a country's macro economic system (3) (Figure 1).

For the successful establishment and analysis of integrated cassava projects, information on the three main integrating systems must be available (Table 1) to define the advantages and the feasibility of national or regional cassava projects and is of critical importance in the determination of project strategy.

Initially, information is required about the macro-economic and institutional development of the national economy. How new developments will affect the present cassava system and how a new cassava system can provide an answer to a country's perceived needs must be understood to develop effective political support and effective project mechanisms in the course of the integrated project. Table 1a summarizes the related study areas plus the most appropriate information sources and indicates the importance of this information for the different managerial steps that were outlined in last years' Cassava Annual Report, as well as for later project evaluation.

For the successful establishment of integrated cassava projects the present cassava system must be defined in detail and its role determined in the establishment of the newly envisaged system. Since integrated projects are targeted towards making it possible for society to benefit from the increased production potential of new cassava technology, a necessary condition for their development is that they do not negatively influence present cassava utilization. However, they should not be completely dependent on the traditional cassava system since this could frustrate their development.

The detailed knowledge of the present system will be a major tool in the identification of target regions and groups within the project and will be instrumental in assessing the major technological and institutional constraints to the successful implementation of the project. This will aid in defining the concrete objectives for project development and institutional organization necessary for its implementation. Knowledge of how traditional cassava markets are developing will improve the data base for the ex post facto evaluations and will further indicate the necessity of integrated projects. Table 1b summarizes the study areas regarding the traditional cassava system, their most feasible information sources and their importance for management and impact evaluation. In those countries or regions where cassava is not presently an important traditional crop analysis of potential production will be based on expert opinion, comparison with other similar micro-regions and experimentally-obtained information.

The third system to be studied is the new production processing-marketing system that the integrated project aims to develop. To overcome the constraints identified in the study of the present cassava system and to achieve the general objectives of the project at the national level, alternative approaches must be developed and tested, for each one of the components of the new production-processing-marketing -system. Special care should be given to the problems with scale differences in production (small farmers) and big demand enterprises in

the case of animal feed or composite flours. The final project strategy should be evaluated on a regular basis, both as regards project progress and on its interaction with the traditional cassava system. Study areas, feasible information sources and their importance for impact and management are summarized in Table 1c.

1.3 Feasible information sources

Since the material available on cassava production, processing and marketing is often insufficient, surveys are one of the major information sources. These surveys can include key-informants, random samples or multiple visits, according to the data available and information needed. Combinations of different information needs form the key to efficient information collection. Case studies are the most appropriate means of obtaining a better understanding of problems involved in integrated cassava projects, especially when confirmed via more generalized surveys. Use of surveys and case studies at the macro level to develop a general project planning frame is excessively costly and time consuming. The focus here necessarily has to be toward use of secondary sources, however inadequate they may be. In the study of the future cassava system, monitoring techniques become of prime importance. These monitoring techniques can be applied to random samples of project participants as well as to deliberately selected groups of special importance.

The remainder of the economics section of this Cassava Annual Report will describe research undertaken to satisfy information needs for such integrated projects. Examples are drawn from the fields of final utilization and marketing/processing of cassava. They concern the analysis of traditional cassava systems as well as the formation of the new cassava system. A short example of the analysis of macroeconomic developments was contained in the 1981 Cassava Annual Report.

2. Market Segment Identification for Cassava as an Animal Feed in Mexico.

Mexico is outstanding among the countries where pork and poultry production, and consequently animal feed production, has grown rapidly. Pork production has grown at an annual rate of 8.9% and poultry production at a rate of 8.0% during the 1970's and early 1980's (Table 2). The resulting growth of balanced animal feed production was around 8% per year. Sorghum production in Mexico grew rapidly (6.2% year) but from a small base and therefore was not able to satisfy the increasing demand. Thus, Mexico has relied on increasing grain imports: in the early 1970's imports of sorghum were virtually zero, by the early 1980's they had reached one and half million tons/year. Further growth of sorghum production is limited by poor soils and competition for land with the Mexican staple, maize.

To improve the self-sufficiency ratio in grains, Mexico wants to rapidly develop cassava production, but the question of the optimal utilization for this increase needs to be answered. Within the prime material market for animal feed, five possible niches were found where cassava could enter:

(1) Dried cassava utilization in cattle feed in the dry season.

(2) Inclusion of dried cassava in balanced feed production by the concentrate industries.
(3) Inclusion of dried cassava in feed mixing by integrated pig/chicken producers.
(4) Fresh or ensilaged cassava utilization by integrated pig producers.
(5) On-farm feeding of dried or fresh cassava to pigs.

To determine which market segment is most attractive several criteria have to be taken into account. First, the absorption capacity of the different markets must be assessed: though it is difficult to obtain precise data on the different segments the absorption capacity seems largest in the concentrate industry, followed by the integrated producers. The absorption capacity of on-farm feeding is less. Though more than half of Mexico's 18 million pigs are found on small holdings, only a limited number are located in potential cassava production zones. The absorption capacity of cattle rearing is strongly determined by the severity of the dry season and is thus unstable.

A second guideline is transport costs. These are high in the case of dried cassava for the concentrate industry, which is largely located to the north, where most of the raw material is presently grown. For integrated producers, these costs could be lower since they are more prevalent in the south, where most cassava would be grown.

In the case of ensilaged or fresh cassava, transport costs are excessive unless it is fed on the farm in which case the transport cost would be zero. Transport costs for cattle feeding would also be low, since cattle are evenly spread throughout the southern part of the country.

A third criterion is the quality requirements of the different segments. Since Mexico's animal feed industry is highly automated, bulk pellet production would be most attractive. This would, however, considerably increase the production costs of dried cassava and the investments needed for project development. On the other hand, integrated producers have less sophisticated mixing equipment and would be able to process unpelleted cassava chips. Quality requirements for cattle are few. In the case of ensilaged cassava, production costs of acceptable silage are rather high, around 60% of raw material costs.

A fourth guideline is the utilization convenience of cassava in the market segments proposed. Since the animal feed industry and the integrated producers are already used to feed mixing, dried cassava will be most convenient for them. The use of ensilaged or fresh cassava, however, is not usual at present and would require adaptation of mixing processes since if it is fed to cattle or on-farm to pigs additional feed-sources must be acquired to balance the diet.

A final but very important guideline is the opportunity cost of the cassava used in a certain market segment. In the case of the animal feed industry or the integrated producers this is the sorghum saved by using cassava. In the case of the cattle utilization, this will be the

cost of the cattle weight loss or the cost of cut and carry-pasture systems. Since at low and intermediate productivity levels ruminant feeding is more efficient on a pasture than on a grain or grain substitute basis these opportunity costs are rather low. In the case of cassava on-farm feeding, it is expected that cassava will replace not only sorghum but considerable quantities of maize. The extreme importance of maize in the Mexican diet and the problems of maintaining self-sufficiency in this crop would make this option very attractive.

The attractiveness of the different market segments to the stated criteria is shown in Table 3 . Cassava feeding for cattle is unattractive. Fresh or ensilaged cassava utilization could be useful in some areas where drying is complicated but will probably be an expensive option. The market segment which looks like the most attractive target is the inclusion of dried cassava in feed mixing by integrated producers. A strategy to enter this market segment could be combined with the development of on-farm feeding of pigs. After experience has been obtained in these two segments, the more demanding but more absorbing animal feed concentrate industry could be tackled.

Considering the two main potential demand sectors, integrated producers and the annual feed concentrate industry, the potential production areas in Mexico were evaluated in collaboration with INIA (Instituto Nacional de Investigacion Agricola). The evaluation of each area was based on: (a) the potential for establishing cassava cultivation; and (b) the potential for establishing a drying industry. Details of the evaluation parameters and their weighting are listed in Table 4 . This evaluation takes into account other factors as well, such as mechanization possibilities, competition with other crops and infrastructure.[a] On the basis of the criteria mentioned in Table 4, a balanced evaluation could be made of those zones, where cassava's potential as an animal feed are best. Zones selected as having immediate or future potential are shown in Figure 2. At present, the Mexican federal department of agriculture (SARH) and INIA are increasing their research efforts in these areas and have started the 20 integrated projects to use cassava as animal feed.

3. Factors Influencing Fresh Cassava Consumption.

3.1 Introduction.

Available data suggest that around one third of the global cassava production is destined for fresh human consumption. Given the diversity of cassava utilization on a global scale, this would make fresh human consumption one of the most (if not the most important) present utilization of cassava. For certain countries the importance of fresh cassava consumption is much higher than this average of one third. For example, it is estimated that 70% of production is destined for fresh human consumption in Cuba, and as much as 96% in the Dominican Republic.

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a Full details are available in "Informe de viaje efectuado a diferentes partes de la Republica Mexicana con el objeto de determinar areas potenciales para la siembra, procesamiento y utilizacion de la yuca." by R. Howeler, W. Janssen and J. Contreras. CIAT mimeo 1984.

Fresh cassava consumption is highly concentrated in rural areas, where it may be 3-5 times higher than in neighboring urban areas (Table 5).

Since many developing countries are rapidly urbanizing, the change from rural to urban fresh cassava consumption patterns can quickly result in a fall in total cassava demand. Consequently, fresh cassava's role as a calorie source in the diet might be less than expected, while at the same time the crop could decrease in importance for income generation of small farmers. Such a development would have major implications for the research strategy of CIAT's cassava program. To understand more precisely which factors are important in determining the differences in cassava consumption between rural and urban areas, and to perceive the implications of this for cassava research, a study to analyze fresh cassava consumption, together with that of some other starchy crops was conducted in the Atlantic coast region of Colombia. Before presenting the results of this study the theoretical framework used in the analysis of the consumption of the different crops will be explained.

3.2 A theoretical model for crop consumption.

To explain the consumption level of different crops by different people two sets of determining factors can be identified. A first set is related to the socio-economic characteristics of the population to be studied. Income per head is among the most important characteristics in this set. Since a major objective of this analysis is to explain the consumption differences between rural and urban environments, the degree of urbanization is obviously an important characteristic. (Other factors of minor importance, which are not included in this analysis are household size and racial/regional origin).

The second set of factors influencing consumption of different crops is related to the appreciation of distinct properties of the crops under consideration. A well recognized factor in this set is the relative price at which the consumer purchases the crop. Other important properties are taste, ease of preparation, year-round availability, price and stability of quality. Appreciation of these properties is difficult to measure and it is even harder to decide *a priori* which of these properties are relevant in explaining consumption.

Given that these two sets of factors determine consumption levels, the following model can be formulated to explain consumption levels of different crops:

Cij = function (Ij, Uj, Pij, Aij, Bij, Cij ....)
where Cij = Consumption level per head of crop i by consumer group j.

Ij = Income per head in consumer group j
Uj = Urbanization degree of consumer group j
Pij = Relative price of crop i for consumer-group j
Aij, Bij, Cij...= Score of crop i on other properties relevant for consumption in consumer group j

Though such a model is superficially straightforward, from a conceptual point of view its actual estimation demands the resolution of several issues, considered in the following section.

3.3 An estimation procedure to explain crop consumption

To measure consumption levels, relative prices, incomes and appreciation of other properties a consumer survey was conducted in the Atlantic Coast of Colombia among 320 households. Consumption of five crops was studied: cassava, plantain, rice, potato and yam. To enable comparison of consumption levels between crops the consumption in kilos per head was converted to calories per head. The crop price per kilo was similarly converted. These procedures are summarized in Figure 3.

Consumer groups were defined by a double stratification scheme. The first stratification considered the degree of urbanization of consumers. Consumers were selected in four different environments: Two large towns with over 400,000 inhabitants each, two middle-sized towns (150,000 inhabitants) four regional centers (30,000 inhabitants) and four local villages (5,000 inhabitants). Within each urbanization stratum, four substrata were drawn according to income per head. Thus sixteen different consumer groups were identified.

To determine other crop properties affecting consumption, consumers were asked whether they agreed or disagreed with 12 different statements for each of the five crops. These statements referred to different properties considered likely to influence consumption. The average survey values per statement and per crop are summarized in Table 6a.

The average survey values per statement, crop and consumer group were organized in a 12 x 80 matrix, which was afterwards treated in a factor analysis with the varimax procedure to clarify the underlying patterns of the answers. This analysis showed that four factors were able to explain 77% of the communality ($\pm$ variance) of the original matrix. The factor loadings of the original statements are shown in Table 6b. After careful analysis, these four factors were defined as representing the following product properties:

(1) Buying inconvenience, strongly associated with statements 1 to 5.
(2) Intrinsic value, associated with statements 6 and 7.
(3) In shop availability, associated with statements 8 and 9.
(4) Short term price appreciation, associated with statement 10.

In the next step, factor scores for each combination of crop and consumer groups were obtained. For simplicity these data are summarized in Table 7. These express the relative value of each crop in each consumer group for the described product properties. Though the absolute values obtained here are not relevant, they do indicate the relative appreciation for the described product properties. From the factor scores in Table 7 it is clear that cassava has an outstanding positive value on "buying inconvenience", while its appreciation for "intrinsic value" and "in shop availability is average. The "buying inconvenience" of rice is low, while its "availability" is well evaluated. Potato is the product with the highest "short run price appreciation" value, indicating that its price has risen in relation to the other product prices.

A linear regression model was formulated in which the calorie consumption per crop in each consumer group was dependent on the average income per head in that group, the price of the crop per calorie and the scores of the crop for the derived factors. Urbanization degree was entered as a dummy variable and through the separate estimation per stratum of price effect, income effect and the "buying-inconvenience" effect. This model can be estimated with Ordinary Least Squares (OLS) if the causal relation between consumption of the different crops is low. The surveyed crops together comprise around 40 to 50 percent of the total calorie consumption and the correlation between consumption of any two crops only had the (expected) negative sign in one case. Therefore estimation with OLS was considered valid. If this had not been the case the formulated model would have been estimated with "Seemingly Unrelated Regressions" (Zellner, 1962).

3.4 Estimation results; analysis and discussion

Preliminary specifications of the linear regression model developed in the former section showed a negative relation between the "intrinsic value" characteristic and the actual consumption. This was probably caused by the fact that crops which are consumed in higher quantities were consistently appreciated less for taste and nutritiousness. The high levels of consumption of these crops might have caused a saturation feeling, in which case the causal relation would be inversed; consumption is no longer determined by the appreciation of its intrinsic value, but the appreciation is determined by the high consumption levels. Therefore the "intrinsic-value" characteristic was eliminated from the analysis.

The estimated parameters of the resulting model and the derived elasticities are shown in Table 8 . The data show that consumption of the crops studied is not highly dependent on income. In big towns where average crop prices are higher than in other areas, consumption of the calorie sources included in the study rises slightly with income. In the other environments consumption falls slightly when income rises. These tendencies are, however, weak and do not allow a significant conclusion on the relation between income and consumption of the crops studied. The relationship between crop consumption and relative prices per calorie is strong. An average price elasticity of -0.65 is estimated, indicating that consumers respond fairly sensitively to the relative prices of the products studied. This stresses the validity of strategies directed toward decreasing acquisition costs of food crops as a means to improve nutritional status. The price elasticity-values are highest in the large towns (probably because food prices are high and force people to be more price-conscious) and in the small villages, where prices are relatively high while incomes are low.

Availability is strongly and positively related with consumption, as expected. Rice especially has a high score on this factor (see Table 7) i.e. its high availability has a positive impact on its consumption of 12 kg/capita/ year. Yam and plantain score badly on this factor and their consumption could thus be restricted by their poor availability.

The negative sign of the "short term price appreciation" is also as expected. Where consumers had the impression that the price of a

crop had risen, consumption had dropped. Potato and yam were supposed to have had unfavorable price developments and consequently faced consumption decreases.

The "buying inconvenience" factor has special relevance in the analysis since cassava, the target crop for this research, scores a very high value and consequently would find its consumption significantly reduced for this reason. To estimate whether "buying-convenience" is of equal importance in different environments this factor has been estimated per urbanization stratum. The impact of a certain difference in the measured "buying inconvenience" would be about similar in large and intermediate towns but slightly less in the large villages. In the small villages, the relation between "buying inconvenience" and consumption would be positive, implying that the more inconvenient a product, the more it is consumed. Since the estimated parameter for the small villages is not significant this probably means the "buying convenience" does not have a significant effect on consumption in this environment. The effect of cassava's "buying inconvenience" has been estimated by calculating the impact of a 50% reduction in cassava's score on this factor in comparison with the next highest factor score of the crop in this survey (i.e. yams). Since "buying inconvenience" was assessed higher in the large towns, the effect would be biggest here, around a 16 kg/ head per year decrease in consumption. In intermediate towns and large villages the effect would be respectively around 11 and 9 kg/head per year.

Available evidence suggests that cassava's "buying inconvenience" is strongly related with its rapid postharvest deterioration. Effective research to control this adverse quality factor would not only decrease the present marketing costs of fresh cassava but simultaneously convert the crop into a much more attractive product for urban consumers i.e. reduce its "buying inconvenience". In this way, fresh cassava storage technology could allow cassava to mantain its role as a staple calorie source in many different countries, even where urbanization continues as rapidly as at present.

Table 1. A schematic presentation of information needs in integrated cassava projects

1A: Information needs on the macro economic development	Information sources	Input in management of integrated projects	Input in economic impact studies	General objectives of information gathered
- Demand studies for food/feed calories and definition of best target utilisation	- Secondary sources	Development of macro planning frame	ex-ante	1) To determine national desirability and feasibility of integrated cassava project financing
- Production studies of alternative calorie sources	- Secondary sources - Case studies	Development of macro planning frames		
- Balance of payment studies and analysis of the need for more efficient utilisation of domestic resources	- Secondary sources	Development of macro planning frame		2) First estimation of ex-ante impact of integrated project
- Production cost approximations in different demand strata	- Synthetic budgeting - Case studies - Secondary sources	Development of macro planning frame Appropriate phasing of activities		3) To defined overall strategy and objectives of project
- Study of political willingness of government to develop cassava	- Interviews - Policy-documents	Assessment of institutional capacity Project financing		
- Assessment of support mechanisms for integrated cassava projects	- Interviews - Description of governmental policy-execution	Assessment of institutional capacity Project financing Support activities		
1B: Information needs on traditional cassava production processing-marketing systems				
- Technical and economic assessment of traditional cassava production within farm system	- Survey - On farm research - Case studies	Appropriate phasing of activities Support activities	ex-ante ex-post	1) To define project zones and project target farmers
- Assessment of present access to market of cassava growers	- Surveys - Case studies	Appropriate phasing of activities		2) To identify constraints in project development and to derive operational objectives
- Technical and economic assessment of present cassava processing/marketing	- Case studies - Structure/conduct performance analysis	Appropriate phasing of activities		3) Re-examination of ex-ante impact
- Studies on size and development of present cassava markets	- Secondary sources - Surveys	Development of macro planning frame Appropriate phasing of activities		4) To develop base-line material for project evaluation
- Studies on present institutional services and support to cassava growers	- Surveys - Studies on institutional operations	Assessment of institutional capacity Support activities		
1C: Information needs on the cassava production processing-marketing systems				
- Assessment of alternative improved cassava production systems within the farm	- On farm research - Case-studies - Surveys	- Replication and monitoring - Support activities - Appropriate phasing of activities	ex-post	1) To design and establish new cassava production-processing marketing systems
- Assessment of improved/new processing-marketing-techniques at different technological levels	- Pilot plants - Pilot marketing scheme	- Replication and monitoring - Support activities - Appropriate phasing of activities		2) To develop post-project data base for project evaluation
- Assessment of different market segments and demand followed by identification of target buyers.	- Surveys - Secondary sources	- Replication and monitoring		
- Assessment of scale accommodation in new cassava systems of small scale production large scale utilisation	- Structure conduct performance analysis - Market organization-studies	- Replication and monitoring - Support activities		3) To estimate ex-post impact of integrate projects
- Assessment of extension programs and credit lines	- Study of institutional operations	- Support activities - Replication and monitoring		4) To guide development of other integrate cassava projects
- Assessment of interaction with traditional cassava system	- Surveys - Case studies	- Replication and monitoring		

Table 2 . Development of pork and poultry production, concentrate production, sorghum production and imports in Mexico, 1970-1982.

Year	Pork production (000 tons)[a]	Poultry production (000 tons)[b]	Concentrate production by organized industry [c]	Concentrate production by integrated producters [d]	Sorghum production (000 tons) [e]	Sorghum imports (000 tons) [f]
1970	-	-	2135	1921	2747	12
1971	-	-	2242	2009	2516	9
1972	573	216	2235	2129	2612	221
1973	641	229	2650	2292	3270	0
1974	719	248	2850	2432	3499	474
1975	810	296	3150	2715	4126	845
1976	909	289	3500	3166	4027	0
1977	1010	311	3780	3507	4325	749
1978	1085	336	3930	-	4193	922
1979	1167	367	4076	-	3994	1174
1980	1251	399	4220	-	4689	1341
1981	1307	431	4647	-	6296	2062
1982	1365	483	4550	-	4717	1371
% annual growth	8.9	8.0	7.1	10.3	6.2	n.a.

Sources : a and b . Estadística del Subsector Pecuario en los Estados Unidos Mexicanos, Dirección General de Economía Agrícola, SARH, México, various years.

c and d . "La Industria Alimenticia Animal en México", CANACINTRA, México, 1982 and "El Desarrollo Agro Industrial y los Insumos Estrategias para el Sector Agropecuaria-Alimentos Balanceados". SARH, Mexico 1979.

e and f . "El Sector Alimenticio en México", Secretaría de Programación y Presupuestos, Coordinación General de los Servicios Nacionales de Estadística, Geografía y Información, 1981.

Table 3. Attractiveness of different possible cassava market segments to different criteria in Mexico.

	Absorption capacity[a]	Transport costs	Quality requirements	Utilization convenience	Opportunity costs of cassava utilizations
Dried cassava utilization in dry season cattle feeding	-	+	+	-	--
Inclusion of dried cassava in balanced feed production by concentrate industry	++	-	-	++	+
Inclusion of dried cassava in feed mixing by integrated pork/chicken producers	+	±	+	++	+
Fresh or ensilaged cassava utilization by integrated pig producers	±	--	±	-	+
On-farm feeding of cassava to pigs	±	++	++	-	++

[a] ++ : Very attractive for mentioned criterion
+ : Very attractive for mentioned criterion
± : Relatively indifferent on mentioned criterion
- : Inattractive for mentioned criterion
-- : Very unattractive on mentioned criterion

Table 4. Weighted evaluation parameters for establishing cassava cultivation and a drying industry in Mexico.

		Weight
The potential to establish the cultivation of cassava		
- Expected production of cassava	Yield/hectare (tons)	medium
	Profits/hectare (pesos)	high
	Projected hectares	high
- Production alternatives	Most common crop/profits/ hectare (pesos)	high
	Second most common crop/ profits/hectare (pesos)	high
- Availability of land	Size of farms in the zone (ha)	low
	Land tenure (% ownership)	medium
	Land in stubble/fallow (% of farm)	medium
- Possibility of mechanization	Availability of tractors (number/1000 ha)	medium
- Institutional presence	Number of representatives (DT/1000 ha)	medium
	% of crops presently financed	medium
The potential to establish a cassava drying industry		
- Availability of appropriate technology	Number of months for drying (number)	high
	Fuel/price (pesos/calorie)	high
	Availability of regional technical investigation	low
- Transport infrastructure	Quality of roads in dry season	low
	Quality of roads in wet season	low
- Access to the concentrate prime material market	Distance to the closest Albamex plant (km)	medium
	Installed capacity closer than 250 km (ton)	high
	Installed capacity in the State (ton)	medium
	Number of animals closer than 250 km (000 pigs)	high
	Number of animals in the state (000 pigs)	medium
	Availability of sorghum in a free market without transport subsidy	high
- Level of organization	Presence of cooperatives/good "ejidos"	medium
	Educational level	medium
	Presence of alternative methods to dry cassava	low
- Competition with other industries	Cost of manual labor/day (pesos)	high
	Level of unemployment (%)	medium

Table 5. Consumption of fresh cassava in Latin America by country average rural, urban and national consumption per head (kg/year).

Country/year	Average rural	Average urban	Average national
Bolivia (72)	17.0	5.4	15.3
Brazil (75)	11.2	2.7	6.3
Colombia (70)	35.0	16.5	20.4
Cuba (76)	30.0	12.4	18.8
Dominican Republic (75)	43.3	20.0	33.1
Ecuador (74)	31.0	6.0	19.0
Paraguay (76)	180.0	35.0	110.1
Peru (76)	18.3	5.6	11.0
Venezuela (75)	27.4	5.0	9.8
Total	19.1	5.9	11.4

Source: John K. Lynam and Douglas Pachico (1982): Cassava in Latin America Current status and future prospects, CIAT unpublished document.

Table 6. Key data on statements to measure important product properties in which 6a refers to average percentage agreeing statement for each crop; and 6b refers to loadings of the different statements on the derived factors

Statement	6a = % consumers in agreement					6b = Loading of statemetns			
	Rice	Potato	Cassava	Plantain	Yam	Factor 1	Factor 2	Factor 3	Factor 4
1) To buy this product is always risky for quality reasons	2.8	13.4	75.9	3.4	26.6	0.96	-0.08	-0.05	0.04
2) Thisk products cannot be kept well	0.3	19.3	94.5	12.1	11.8	0.89	-0.01	-0.02	-0.14
3) Of this products a lot is wasted in the preparation	0.0	30.2	48.8	2.9	48.5	0.74	0.08	-0.17	0.47
4) The quality of this product varies strongly	13.7	20.2	87.6	5.6	32.6	0.94	-0.14	0.00	0.03
5) This product is bought on the day of consumption	60.7	58.8	87.5	62.8	61.6	0.59	-0.07	0.07	-0.11
6) This product is very tasty	55.0	66.2	67.1	82.9	59.0	0.10	0.88	0.19	0.10
7) This product is very nutritious	11.6	46.4	51.5	9.19	15.6	-0.28	0.87	-0.04	-0.09
8) This product is always available	91.0	74.2	67.7	77.4	56.5	-0.17	0.06	0.86	-0.14
9) This product is easy to prepare	65.5	64.9	77.4	60.9	55.0	0.44	0.32	0.69	-0.04
10) The price of this product has risen slowly in the last few years	25.1	33.1	24.5	31.0	15.5	-0.21	0.11	0.03	0.89
11) This product has a constant price	35.6	31.0	12.7	10.6	4.7	-0.29	-0.35	0.56	0.27
12) This product is indispensable in your daily meals	79.6	53.3	61.9	83.9	44.6	-0.22	0.26	0.51	-0.59
Communality estimation	-	-	-	-	-	3.97	1.86	1.85	1.51

Table 7. Factor scores per crop, average values of total sample.

Crop	Factor 1 "buying inconvenience"	Factor 2 "intrinsic value"	Factor 3 "in shop availability"	Factor 4 "short term price-appreciation"
Rice	-0.77	-1.00	0.85	-0.64
Potatoes	-0.35	0.08	0.00	1.20
Cassava	1.75	-0.18	0.05	0.42
Plantain	-0.69	1.42	-0.26	-0.75
Yam	0.06	-0.32	-0.89	0.64

Table 8. Estimation results of a model that relates crop consumption with different product properties in which the dependent variable is crop consumption per head in calories

	Estimated parameters							
Total sample :	Income per head (Col pesos/month)	Price (Col pesos/ calories)	Factor 1 (buying inconvenience)[a]	Factor 3 (availability)	Factor 4 (price assessment)	Derived income elasticity	Derived price elasticity	Impact on cassava consumption of improvement of shopping convience[b] (kg/year)
	-	-	-	38192 (4.10)	-26710 (2.38)	-	-	-
Urbanization strata								
large towns	0.60 (0.27)	-2218765 (1.54)	-26544 (2.50)	-	-	0.04	-0.69	+ 15.6
intermediate towns	-3.20 (1.03)	-3044723 (2.21)	-26937 (2.28)	-	-	-0.17	-0.66	+ 10.9
large villages	-3.83 (1.00)	-3345119 (1.92)	-18556 (1.54)	-	-	-0.17	-0.62	+ 8.8
small villages	-2.67 (0.69)	-2812951 (2.21)	+ 8701 (0.59)	-	-	-0.13	0.70	- 4.4

t - values are put in parenthesis $R^2 = 0.69$ $F_{12}^{79} = 10.34$

a To understand the impact of the factors included, one should consider the factor-sources mentioned in Table 7. The impact of the factor "buying inconvenience" is 26000 calories (17 kg of cassava) for each point of difference. In urban areas cassava scores for this factor are on the average 1.7 points higher than for other crops, which would decrease their consumption by about 30 kg/head/year. Halving this difference would then increase cassava consumption by about 15 kg/head/year in urban areas.

b To estimate the impact of improvement of buying convenience it was supposed that the difference of cassava's score on inconvenience with the next most inconvenient crop in a certain stratum wold be halved.

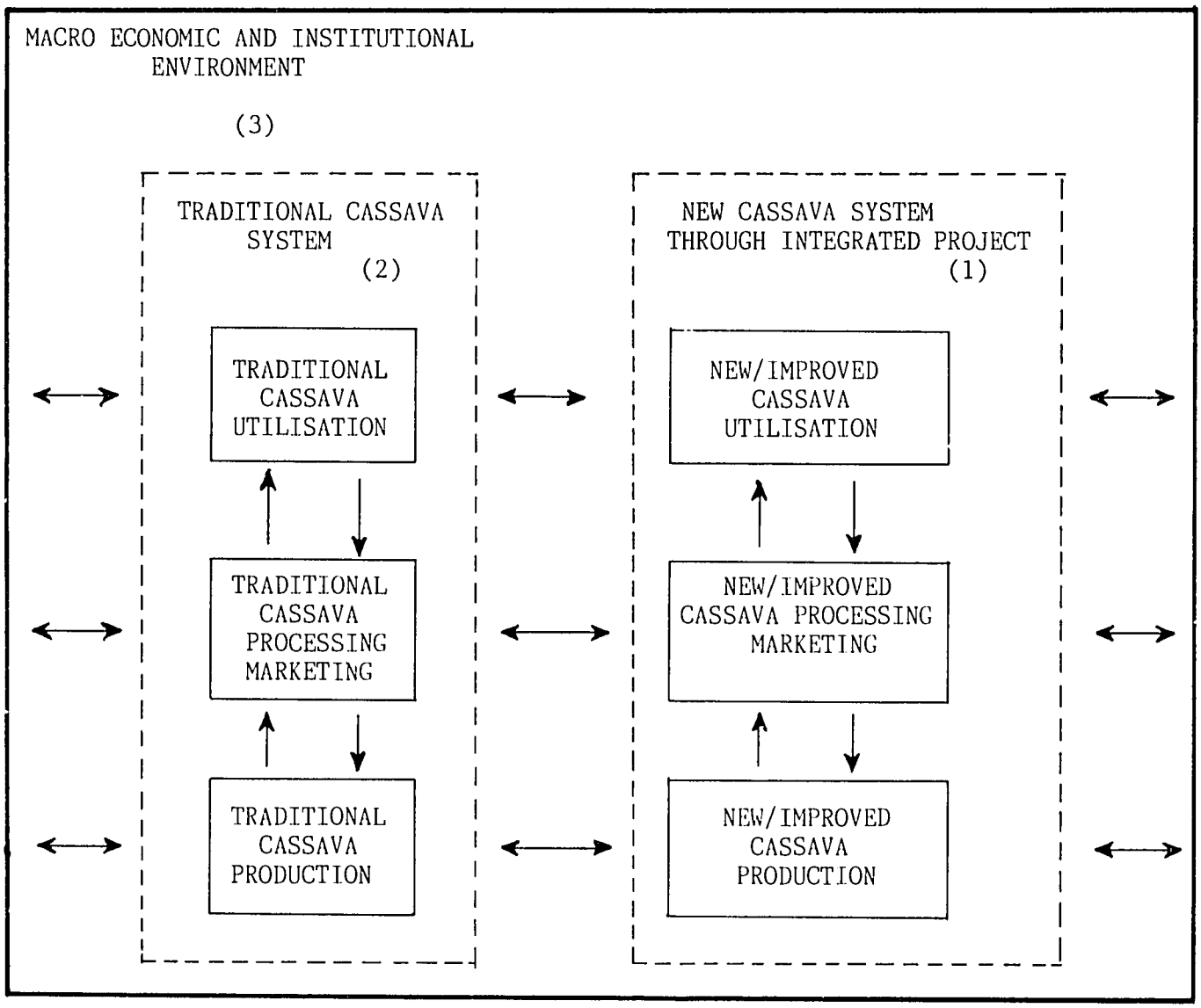
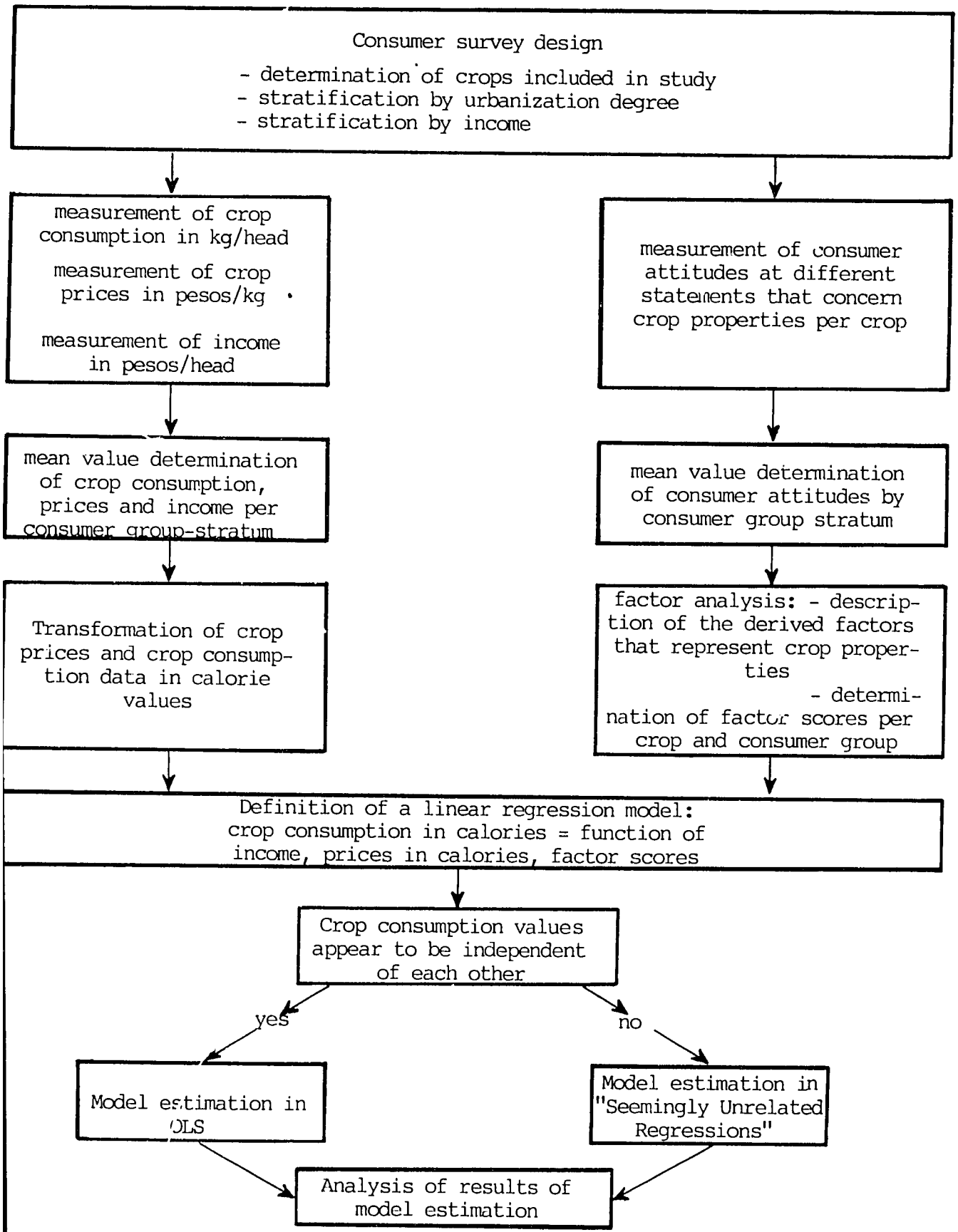


Figure 1 : The three main interacting systems in integrated cassava development projects.

Figure 2. A procedure to estimable influence of crop properties on crop consumption



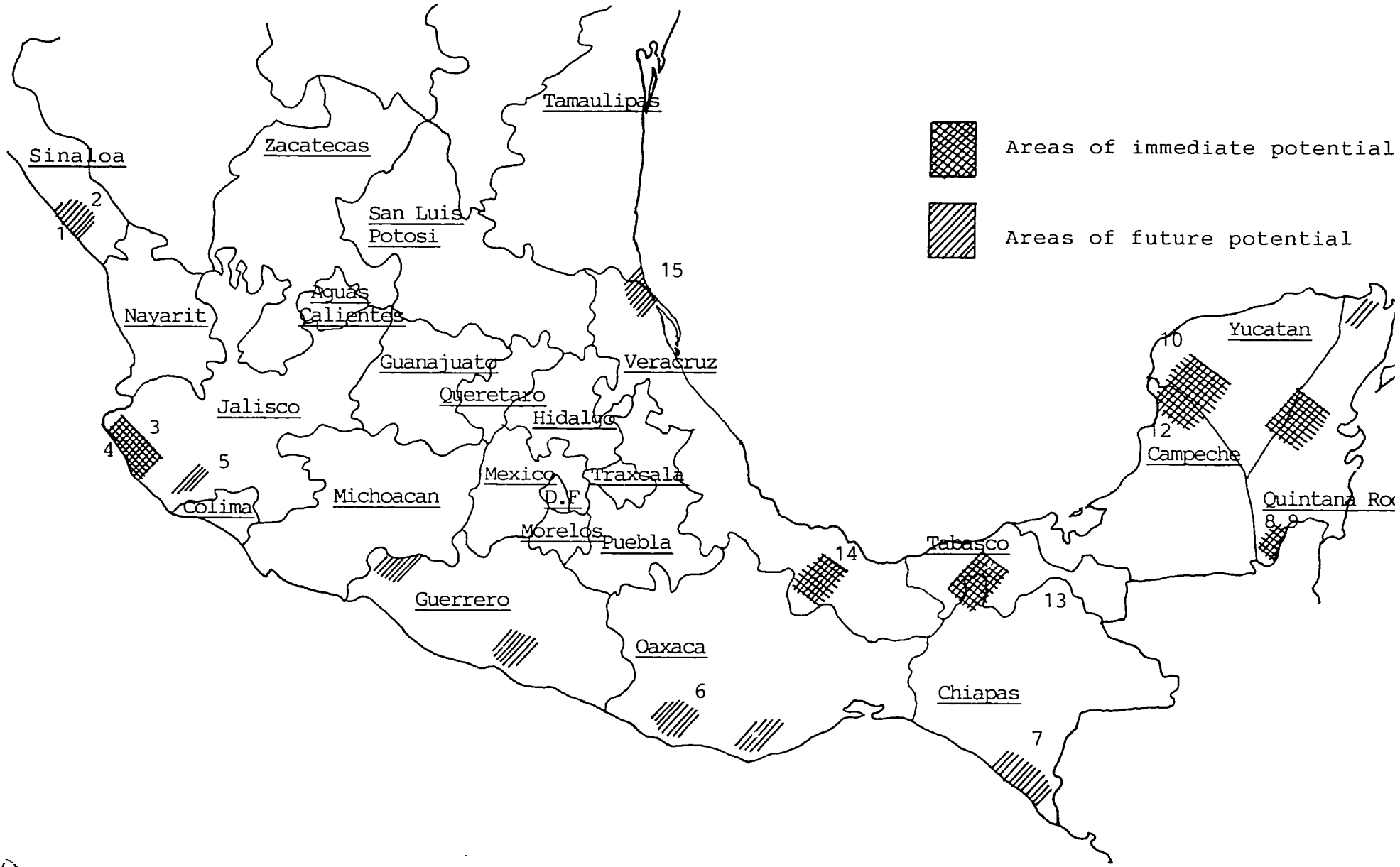


Figure 3. The Republic of Mexico indicating the areas with immediate or future potential for the production of cassava.

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* Left during 1984